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NASA Lewis Icing Research Tunnel User Manual

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1.0 Introduction

This manual describes the Icing Research Tunnel (IRT) at Lewis Research Center and provides information for users who wish to conduct experiments in this facility. The Aeropropulsion Facilities and Experiments Division (AFED) manages and operates the facility. The capabilities of the tunnel test section, main drive system, speed control system, and spray bars are described. Tunnel performance maps showing liquid water content (LWC) as a function of median volume droplet (MVD) size are presented for two types of spray nozzles at test-section velocities ranging from 86.8 to 303.9 kn (100 to 350 mph). Facility support systems, which include heated air systems, steam and service air systems, an altitude exhaust system, a force balance system, and a model electrical power system, are described. Facility instrumentation capabilities for measuring temperature and pressure and simulating model attitude are discussed. Photographic documentation and flow visualization techniques are also described. Pretest meeting formats and schedules are outlined. Tunnel-user responsibilities, personnel safety requirements, and types of test agreements are also explained.

The IRT is a closed-loop atmospheric tunnel that is equipped to support the low-speed testing of models. It has a rectangular cross section that is 6 ft high, 9 ft wide, and 20 ft long. The velocity of air in an empty test section can be controlled from 43.4 to 373.4 kn (50 to 430 mph).

NASA Lewis Research Center is located adjacent to Cleveland Hopkins International Airport in Cleveland, Ohio. The IRT, Building 11 in figure 1, can be serviced by air and motor freight. A schematic of the tunnel, shop, and control room is given in figure 2. Those desiring to schedule test time in the facility should contact the IRT facility manager 1 year in advance to permit NASA Lewis time to review the proposed model design and test envelope and to draw up a schedule (see appendix A).

During a given test program, NASA Lewis can provide complete security for proprietary or Government-sensitive information. Personnel access to the wind tunnel test chamber, test section, and control room can be tightly controlled. However, requirements for security must be discussed with the NASA Lewis IRT facility manager at the pretest meeting. The topics to be discussed at the pretest meeting are thoroughly covered in section 6.1.

2.0 Description of IRT

2.1 General Description

The NASA Lewis IRT building is a two-story structure that is connected to a balance chamber (fig. 2) by an airlock chamber and a model access door. The shop area on the first floor is available for model buildup. It has a 10.5-ft-wide by 10.67-ft-high model delivery access door located on the east side of the building (fig. 1). The balance chamber is a three-story structure whose first-floor layout is shown in figure 3. There is an access door on the east side of the balance chamber that retracts. The 9.08-ft-wide by 8.25-ft-high opening permits a model to be moved from the shop area into the balance chamber. On the second floor of the balance chamber are the tunnel test section, the tunnel access doorway, and the facility control rooms. A test-section model access hatch and the test-section altitude exhaust duct are located on the third floor. In some instances the model to be tested is too large to enter the test section through the balance chamber third floor access hatch, so the diffuser access hatch is used to insert the model into the tunnel (see fig. 2). This access hatch is 8 ft high by 10 ft wide. As figure 2 shows, the IRT is a closed-loop atmospheric tunnel with rectangular cross sections. The volume inside the entire tunnel is 193 729 ft^3. The test section is 6 ft high, 9 ft wide, and 20 ft long. Figure 4 is a schematic of the IRT showing various tunnel sections and a tabulation of their physical dimensions.

The IRT is able to duplicate the icing conditions in nature that aircraft typically encounter. The conditions are simulated via the refrigeration plant and a spray-bar system that generates a cloud of microscopic droplets of supercooled water. The spray-bar system is described in section 2.6. A sampling of models run in the IRT is shown in figure 5. For more information consult the reports on icing research and tunnel capabilities listed in references 1 through 6.

Figure 1.—Directions to Icing Research Tunnel (IRT)

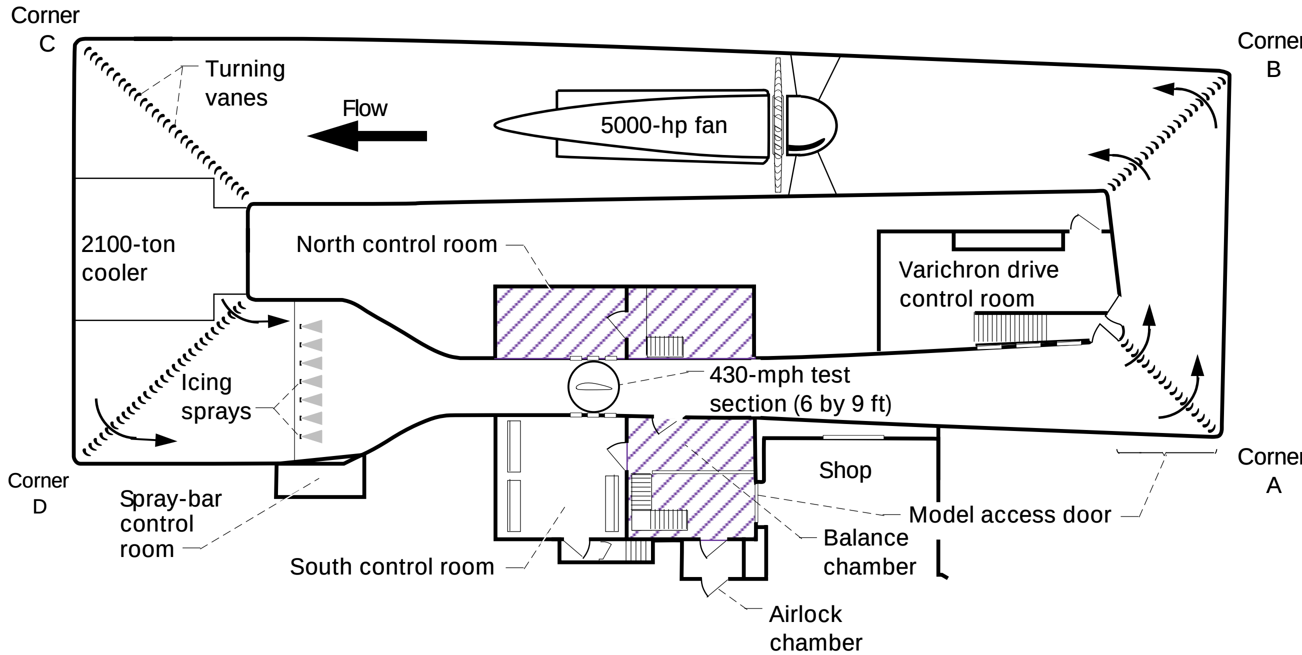


Figure 2.—Plan view of Icing Research Tunnel, shop, and control room sections of IRT building.

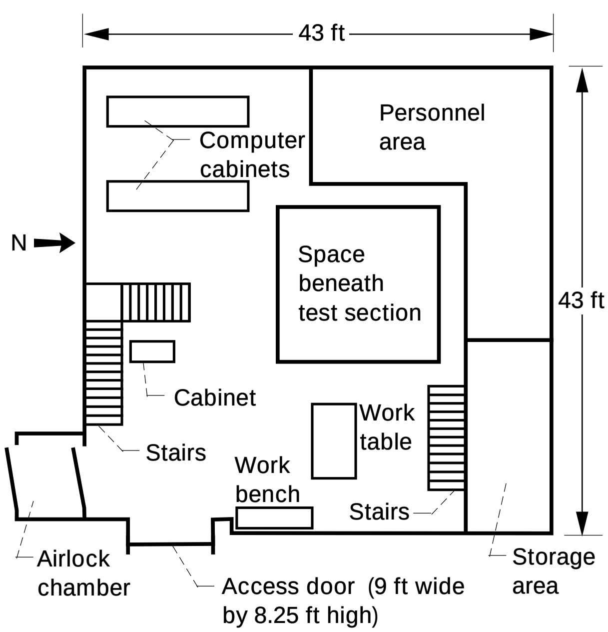


Figure 3.—Plan view of first floor of balance chamber.

WIND TUNNEL CIRCUIT DETAILS

Volume		Dimension, ft	
A	Front leg inlet nozzle	Upstream width Upstream height Downstream width Downstream height Length	29.17 26.17 9.0 6.0 33.83
B	Test section	Width Height Length	9.0 6.0 20.0
C	Test section diffuser	Upstream width Upstream height Downstream width Downstream height Length	9.0 6.0 16.58 13.58 81.50
D	Corner A section (hollow turning vanes - steam heat available)	Upstream width Upstream height Downstream width Downstream height Length	16.58 13.58 16.58 13.58 17.08
E	Crossleg section for corners A and B	Upstream width Upstream height Downstream width Downstream height Length	16.58 13.58 19.0 16.0 26.58
F	Corner B section (hollow turning vanes - steam heat available)	Upstream width Upstream height Downstream width Downstream height Length	19.0 16.0 19.0 16.0 19.5
G	Backleg turning vane diffuser section	Upstream width Upstream height Downstream diameter Length	19.0 16.0 24.83 55.0
H	Fan housing section	Upstream diameter Downstream diameter Length	24.83 26.17 12.92
I	Backleg fan diffuser section	Upstream diameter Downstream width Downstream height Length	26.17 29.17 26.17 38.88
J	Backleg straight section	Upstream width Upstream height Downstream width Downstream height Length	29.17 26.17 29.17 26.17 42.5
K	Corner C section (solid turning vanes)	Upstream width Upstream height Downstream width Downstream height Length	29.17 26.17 29.17 26.17 29.67
L	Crossleg section for corners C and D	Upstream width Upstream height Downstream width Downstream height Length	29.17 26.17 29.17 26.17 14.88
M	Corner D section (solid turning vanes)	Upstream width Upstream height Downstream width Downstream height Length	29.17 26.17 29.17 26.17 29.67
N	Front leg straight section	Upstream width Upstream height Downstream width Downstream height Length	29.17 26.17 29.17 26.17 15.17

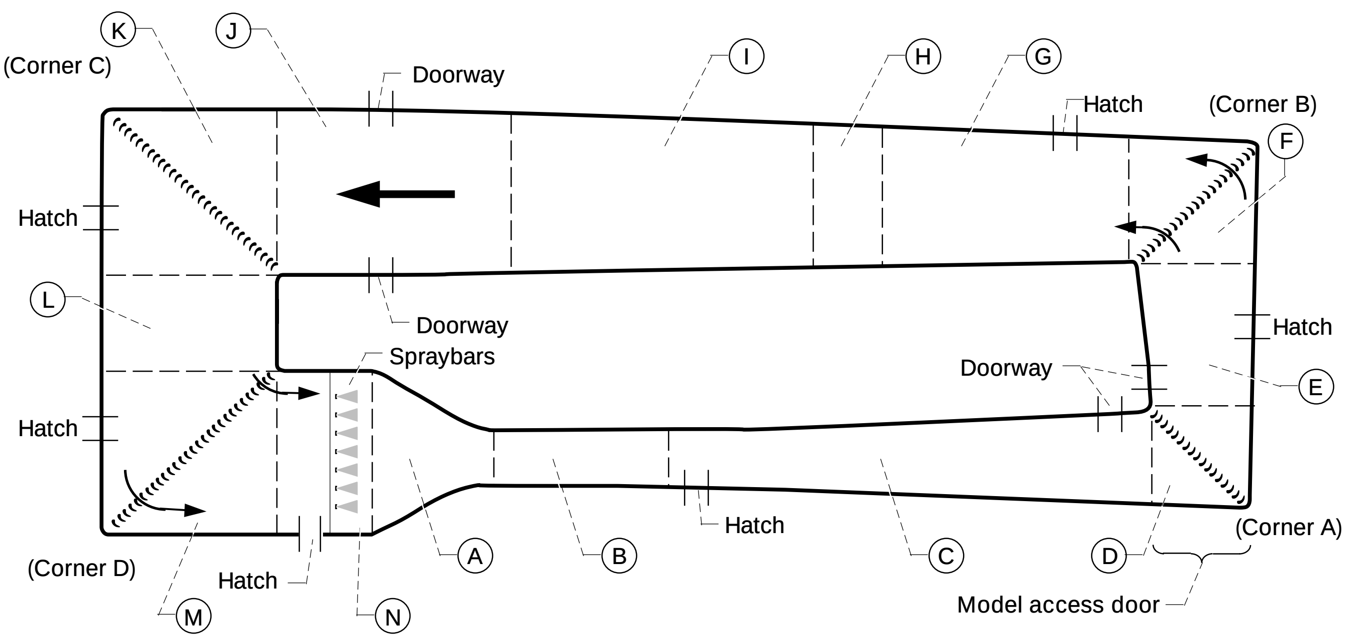


Figure 4.—Wind tunnel volume dimensions and plan view of Icing Research Tunnel showing 14 distinct volumes.

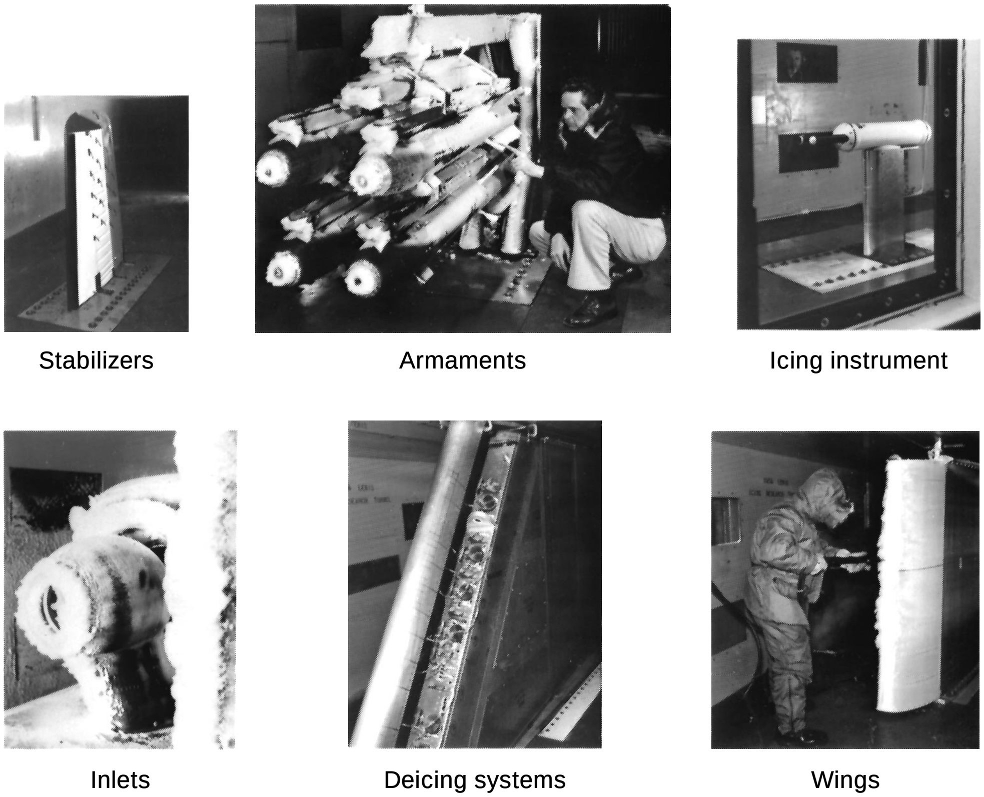


Figure 5.—Aircraft models and experiments installed in test section.

2.2 Wind Tunnel Performance and Capability

The maximum airspeed achievable in an empty IRT test section is 373.4 kn (430 mph). The curves in figure 6 show how the tunnel velocity at the inlet to the test section varies for cylindrical forebody cone models with different amounts of frontal blockage. An estimate of the maximum airspeed achievable in the IRT for various combinations of model blockage and overall drag coefficient can be obtained from figure 7. An estimated maximum operating tunnel condition would be that of a 5-percent-blockage model with a model assembly drag coefficient of 1.7, tested at airspeeds up to 303.9 kn (350 mph) in a temperature and water-droplet environment that simulates natural icing conditions.

The tunnel circuit operates at or below atmospheric pressure, and the test-section total temperature range for chilled air is controlled between -20 and +33 °F.

Data presented in reference 7 show that the vertical Mach number distribution over a test-section survey plane varies less than ±0.005 Mach. In some cases the readings from the instrumentation rake probes nearest the ceiling and the floor of the test section exceeded the 0.005 criterion because of boundary layer effects. Even if these data are included in an uncertainty analysis for data recorded at the vertical centerline of the test-section turntable, the confidence level to achieve a Mach number variation of ± 0.005 or less is 96.4 percent. At present,

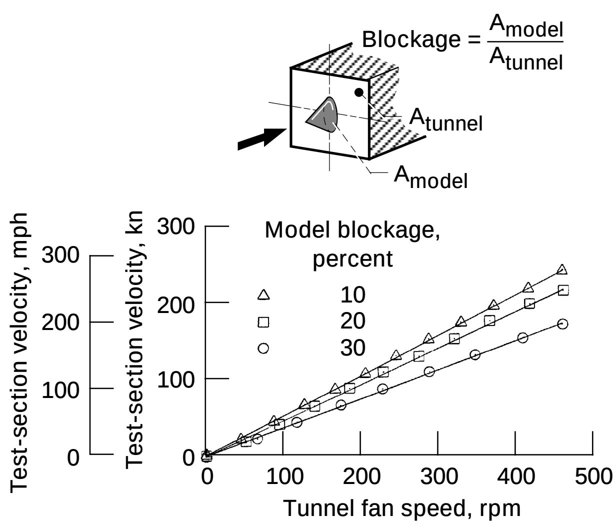


Figure 6.—Average air velocity at test-section inlet.

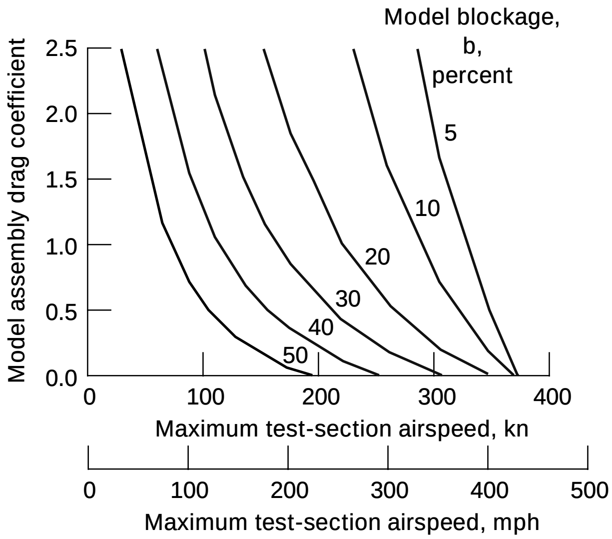


Figure 7.—Estimated effect of test-section blockage and model drag on maximum airspeed in IRT. Fan speed is 462 rpm at sea level static conditions; b = model projected area/54 ft^2; model area = projected area or airfoil area (as defined by user); model drag coefficient = model drag force/(dynamic pressure x model area).

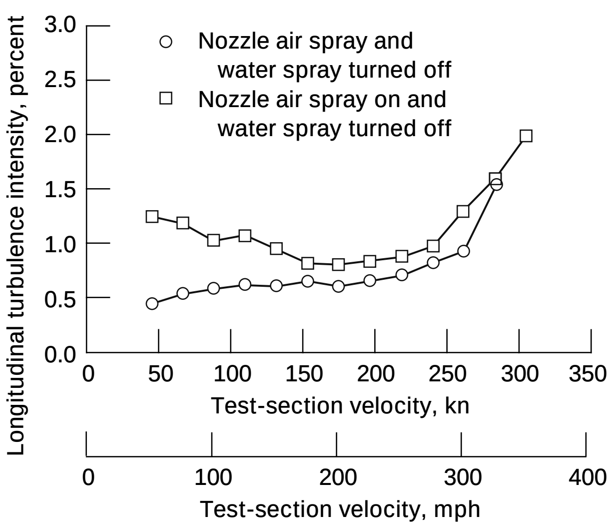


Figure 8.—Longitudinal turbulence intensity in IRT test section (turbulence intensity = [standard deviation of instantaneous velocity fluctuations/mean velocity]).

the test-section region within 6 in. of the ceiling and the floor and less than 18 in. from the sidewalls should be avoided. The tunnel is calibrated periodically, so information more up to date than that found in reference 7 can be obtained from the facility manager. Tunnel turbulence variation with airspeed is shown in figure 8. These turbulence levels were measured with a hot-wire anemometer located 27.25 in. above the test-section floor and 2 in. downstream of the turntable center (106.5 in. from the test-section inlet). Data were recorded with and without spray-bar air pressure. Turbulence intensity levels varied from 0.45 percent at 43.4 kn (50 mph) with both air- and water-pressure spray turned off, to 2.05 percent at 303.9 kn (350 mph) with air spray turned on and water spray turned off.

2.3 Test-Section Details

The view of the IRT test section one sees looking downstream from the spray bars is shown in figure 9. The test section is 6 ft high, 9 ft wide, and 20 ft long. The tunnel area contraction ratio between the cross section at the spray bars and the cross section at the test section is 14.1 to 1.0.

The large balance chamber that surrounds the test section (fig. 2) is at approximately the same static pressure as the test section; therefore, no pressure bulkhead fittings or hermetically sealed connections are needed for the instrumentation leads and service air hoses entering the tunnel test-section ceiling or floor. Personnel access to the test section from the balance chamber is through a 4.5-ft wide by 5.25-ft high door in the south tunnel wall. The south wall of the balance chamber also contains a 4- by 5-ft pressure-relief door that opens to the atmosphere if the altitude exhaust system should fail while in use during tunnel operation. If the difference between atmospheric pressure and the balance chamber pressure reaches 400 lb/ft^2 (psf), a control-room alarm sounds, but if the

Figure 9.—Looking downstream through spray-bar section of Icing Research Tunnel test section.

pressure differential reaches 475 psf, the pressure-relief door opens automatically. The balance chamber is designed for a pressure differential of 600 psfa.

The center of the 8.67-ft-diameter test-section turntable is 106.5 in. from the inlet of the test section. The turntable can be rotated ±20° in the horizontal plane. A plan view of the turntable and model mounting plate is shown in figure 10. Tunnel users must supply a mounting plate to attach the model to the turntable; it must adhere to the specifications shown in figure 11. The mounting plate must contain the mounting holes, as detailed in figure 11, for bolting the plate to the turntable but may contain other holes to accommodate the mounting of the model and routing of instrumentation leads. All models must be fastened to the turntable. A model that is less than the full height of the test section should be fastened to the turntable mounting plate (figs. 10 and 11) and, if required, can be attached to the test-section ceiling. Be advised that all forward-facing surfaces accrete ice; this factor should be considered in the design of the model and its attachments.

The tunnel user must perform a detailed stress analysis on the model support system and provide a copy of the stress analysis to the IRT facility manager and the IRT project engineer 8 weeks prior to the scheduled test (see sec. 7.0).

The test-section ceiling has a hatch that is 4 ft wide by 12 ft long. Through this hatch, models and equipment may be moved into and out of the test section. A 2-ton electric crane located on the third floor of the balance chamber (fig. 2) is available to move models and equipment. Because of rigging constraints, the model profile in the vertical plane is restricted to 71.75 in. (The model should have a hard lifting point, or points, to reduce the amount of rigging required.) Once the model has been properly positioned in the test section, the ceiling hatch cover is fitted into place. Openings in the hatch cover can be fitted with either steel plates or acrylic panels. The acrylic panels allow flow over the model to be monitored via flow visualization equipment (this topic is discussed in sec. 4.5). User-supplied panels of transparent material other than Lucite may be used if safety standards are met. Transparent panels that are to be inserted into the ceiling hatch cover of the test section must conform to the orientation and dimensions shown in figure 12.

An isometric view of the IRT north and south test-section walls showing the visual access windows and the test-section turntable is presented in figure 13. The test-section wall adjacent to the south control room (see fig. 14(a)) contains four windows for observing the model during testing. Three windows are 29 in. wide by 44 in. high, and one window is 24 in. wide by 40 in. high. These four observation windows are electrically heated to prevent fogging. The test-section vertical wall adjacent to the north side control room (fig. 14(b)) contains a doorway and three electrically heated windows through which the tunnel users may view the model during testing. All three windows are 24 in. wide by 40 in. high.

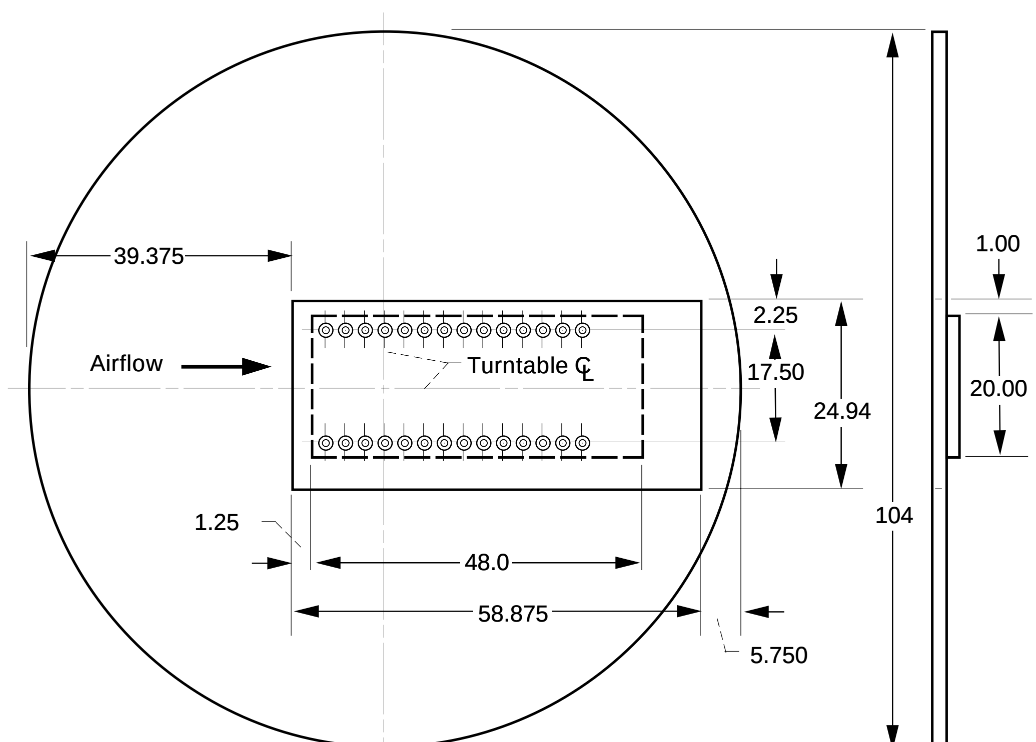


Figure 10.—Icing Research Tunnel turntable and model mounting plate (all dimensions are given in inches).

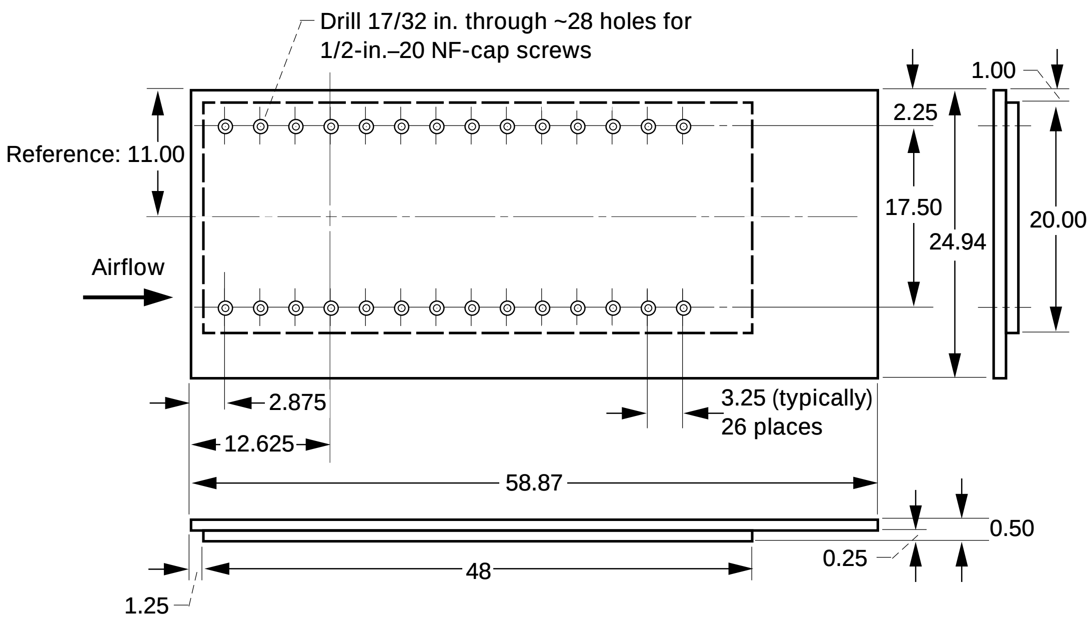


Figure 11.—Icing Research Tunnel model mounting plate. Note: Tunnel is 6 ft high by 9 ft wide. If model extends beyond turntable, leave 1/2-in. clearance above top or below bottom of model (all dimensions are given in inches).

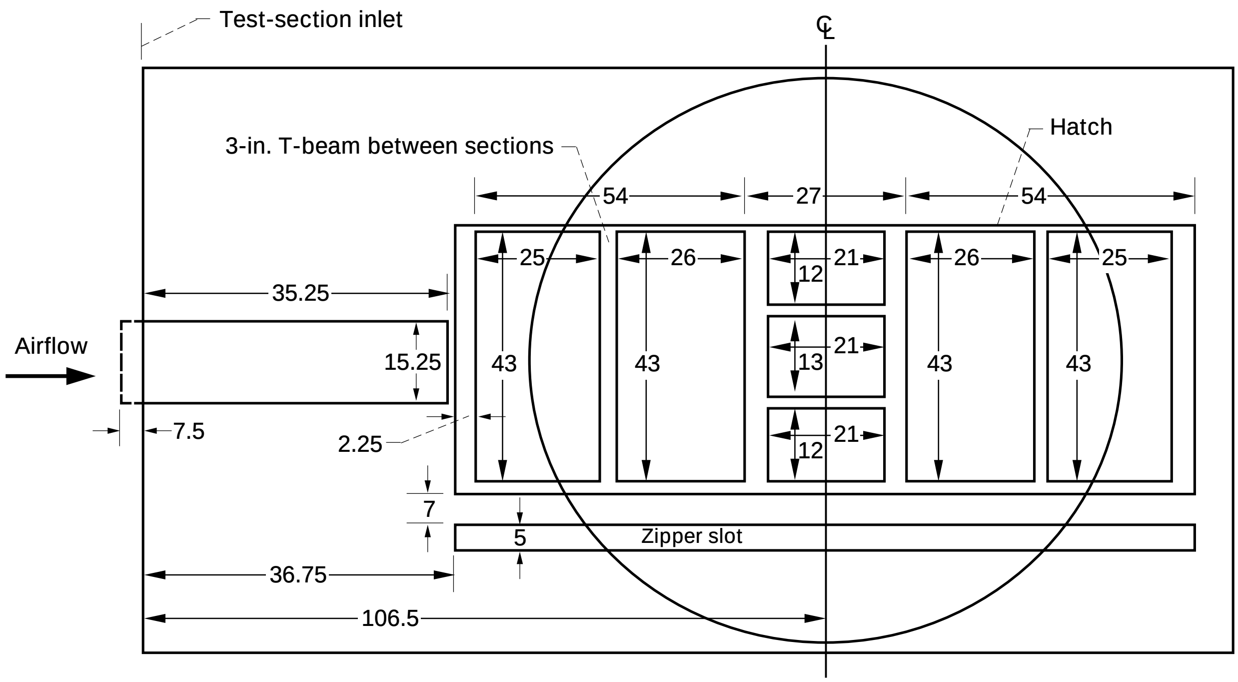


Figure 12.—Access to test section from overhead hatch (all dimensions are given in inches). Note: All support bars between hatch windows, except the small windows across the tunnel, can be removed and reset at 2-in. increments to make any size windows (54- by 43-in. openings can be subdivided into smaller sections in 2-in. increments).

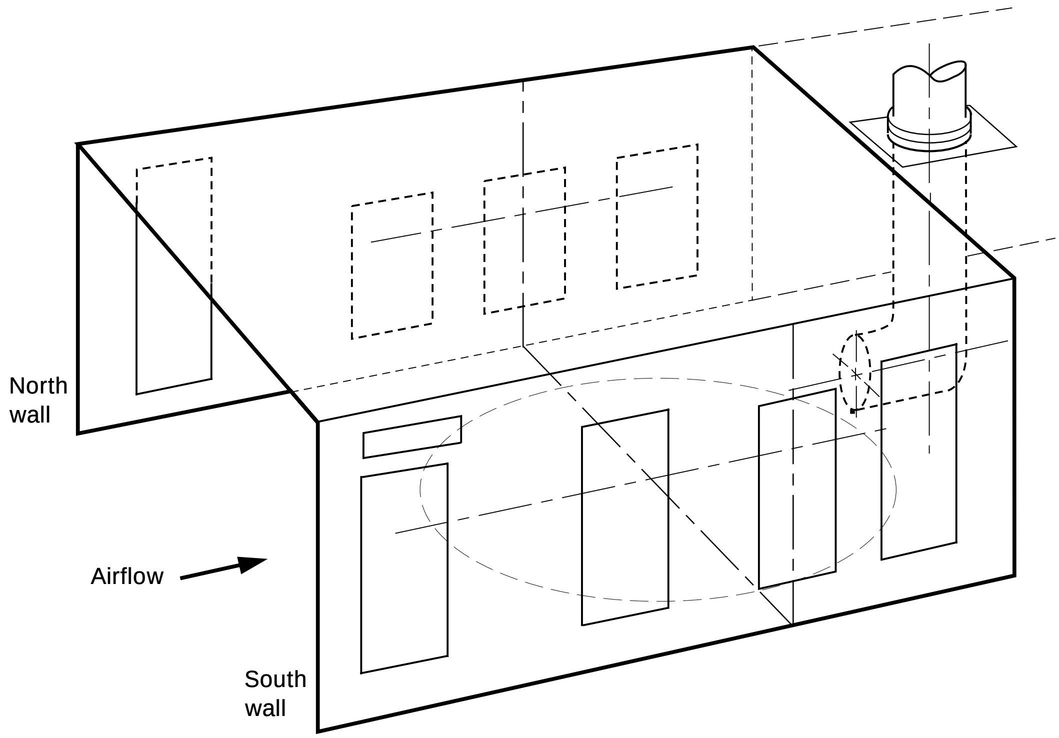


Figure 13.—IRT test-section north and south walls showing visual access windows, turntable, and altitude exhaust piping.

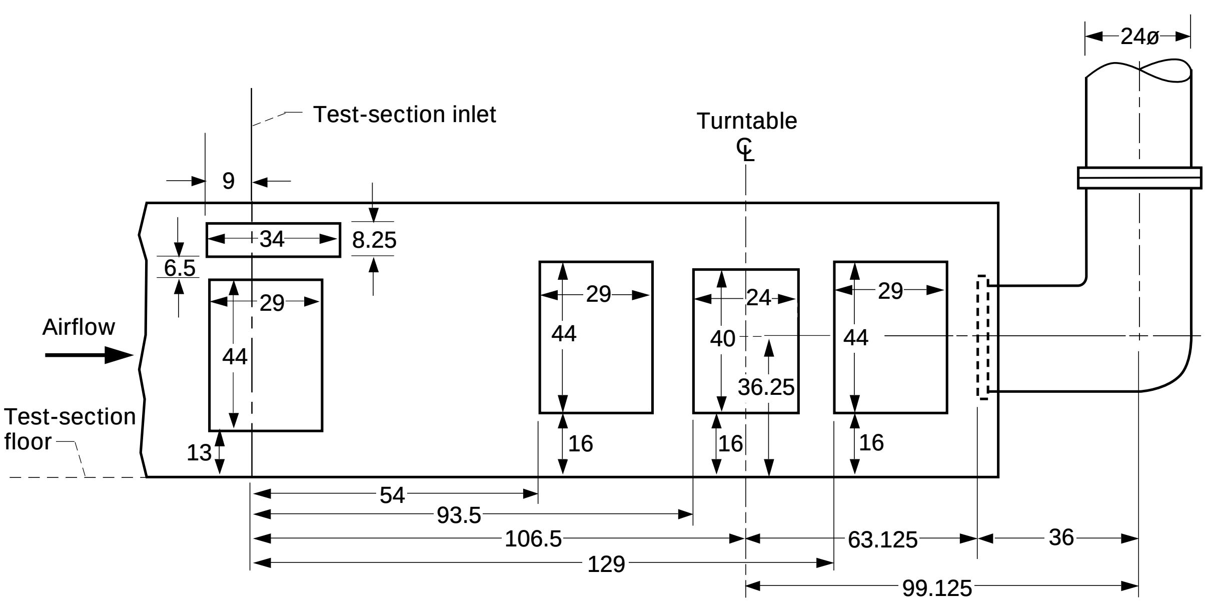


Figure 14(a).—South wall of IRT test section showing four windows as viewed from primary control room (all dimensions are given in inches).

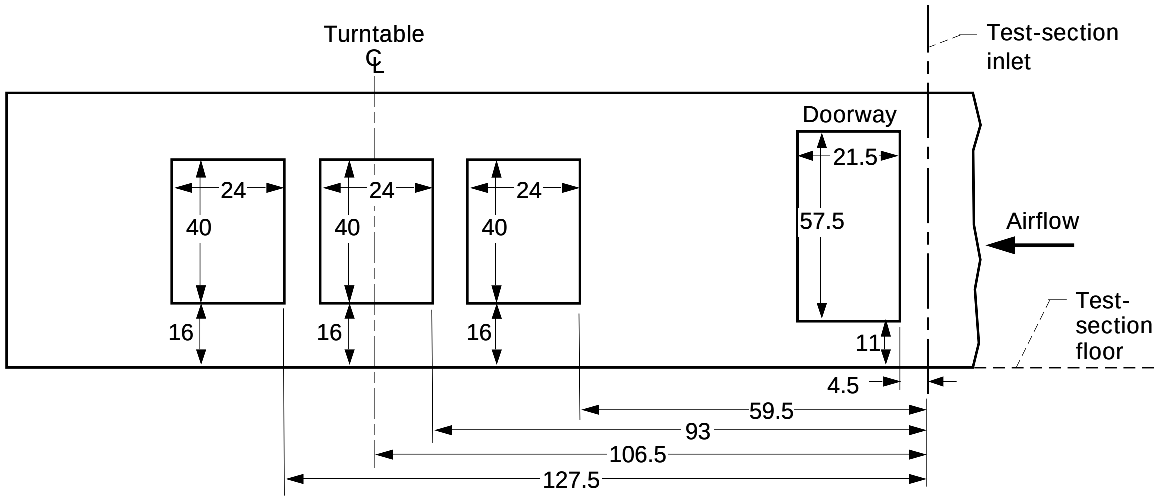


Figure 14(b).—North wall of IRT test section showing three windows and doorway as viewed from secondary (tunnel-user) control room (all dimensions are given in inches).

Figure 15.—IRT fan exit as viewed from corner C of the tunnel (See fig. 2).

2.4 Main Drive System

The major components of the main drive system (fig. 15) are the motor, the fan blades, and the fan inlet guide vanes. The variable-speed motor, which is air-cooled and rated at 5000 hp, is installed inside the faired nacelle. It is controlled from the operator's console in the control room. From this console, the drive motor can be started and stopped and the motor speed can be adjusted throughout a given tunnel experiment. The main drive motor is directly coupled to a fixed-pitch, 12-bladed fan fabricated from laminated Sitka spruce. The fan's diameter is 25.17 ft, and its maximum rotational speed is 460 revolutions per minute (rpm).

2.5 Test Airspeed Control

Two electrically heated pitot-static probes positioned at the inlet to the tunnel test section are used to measure the total and static pressures and to compute the test-section free-stream velocity. At the start of a test program, with the model installed in the test section, an aerodynamic test is run in order to establish a relationship between test airspeed and fan speed in revolutions per minute. Data are recorded for conditions up to 110 percent of desired airspeed or the maximum tunnel conditions. The tunnel operator uses this relationship to select a fan speed that will achieve the desired test airspeed. The fan speed can be accurately controlled to within ±1/2 rpm of the desired value, and can be ramped from 50 to 460 rpm. The nominal ramp rate setting is 4 rpm/sec, but it can be adjusted to values ranging from 1 to 10 rpm/sec. This capability may be used to simulate a flight profile. Note, however, that this ramping capability is not a normal fan operating condition and must be prearranged and approved by the IRT project engineer.

2.6 Spray Bars

Air-assisted water spray nozzles are used to produce the proper sized droplets in the icing cloud. Eight spray bars with a total of approximately 90 nozzles produce a uniform icing cloud in the test section. Either standard or modified (mod-1) nozzles can be installed in the spray bars; the only difference between them is the diameter of the nozzle water tube. Cross sections of a spray bar and nozzle are shown in figure 16. The standard nozzles are used to produce a higher LWC in the test section; the mod-1 nozzles are used to produce a lower LWC. All nozzles of each type are calibrated individually; only those with flow coefficients that vary no more than ±5 percent are selected for use.

The uniform icing cloud produced in the test section by the standard nozzles is approximately 2.5 ft high by 4 ft wide. That produced by the mod-1 nozzles is approximately 2.5 ft high by 5 ft wide. The LWC varies by no more than ±20 percent within these uniform test-section regions. Figure 17 shows test-section LWC contour maps obtained with the standard and mod-1 nozzles. The contour maps were developed by measuring ice accreted on nine evenly spaced, rotating vertical cylinders. Dimensionless values were determined by dividing the ice accretion at a given location in the test section (i.e., LWC) by the ice accretion at the center of the test section (LWC_c). Icing cloud envelopes for the standard and mod-1 nozzles are presented in figure 18. These envelopes show the range of LWC (in grams per cubic meter) as a function of MVD size (in micrometers) for test-section airspeeds of 86.8, 173.7, and 303.9 knots (100, 200, and 350 mph). As can be seen from figure 18(b), LWC levels attainable with the mod-1 nozzles are significantly lower than those attainable with the standard nozzles (fig. 18(a)). It should be noted that LWC levels are highly dependent on airspeed. A more detailed discussion of these envelopes is presented in reference 8. Both MVD and LWC values outside of the ranges shown in figure 18 are

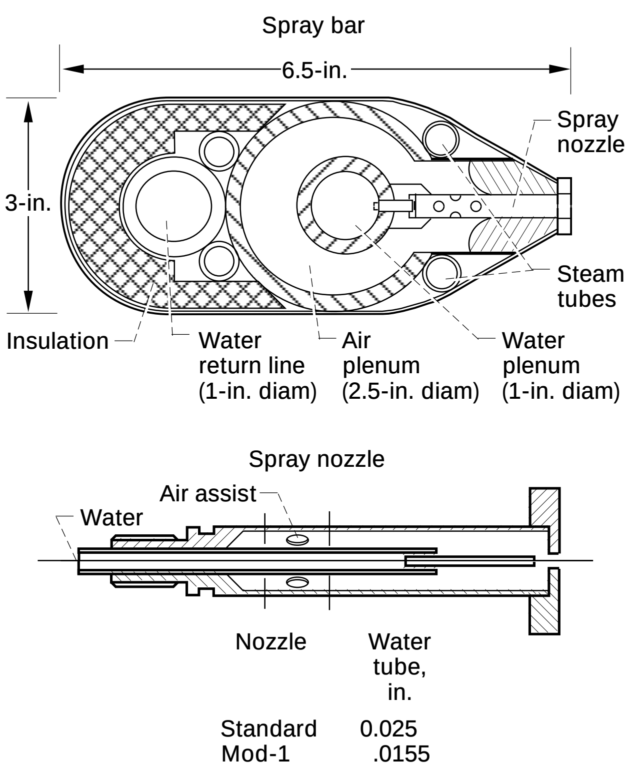


Figure 16.—Schematic of an IRT spray bar and nozzle.

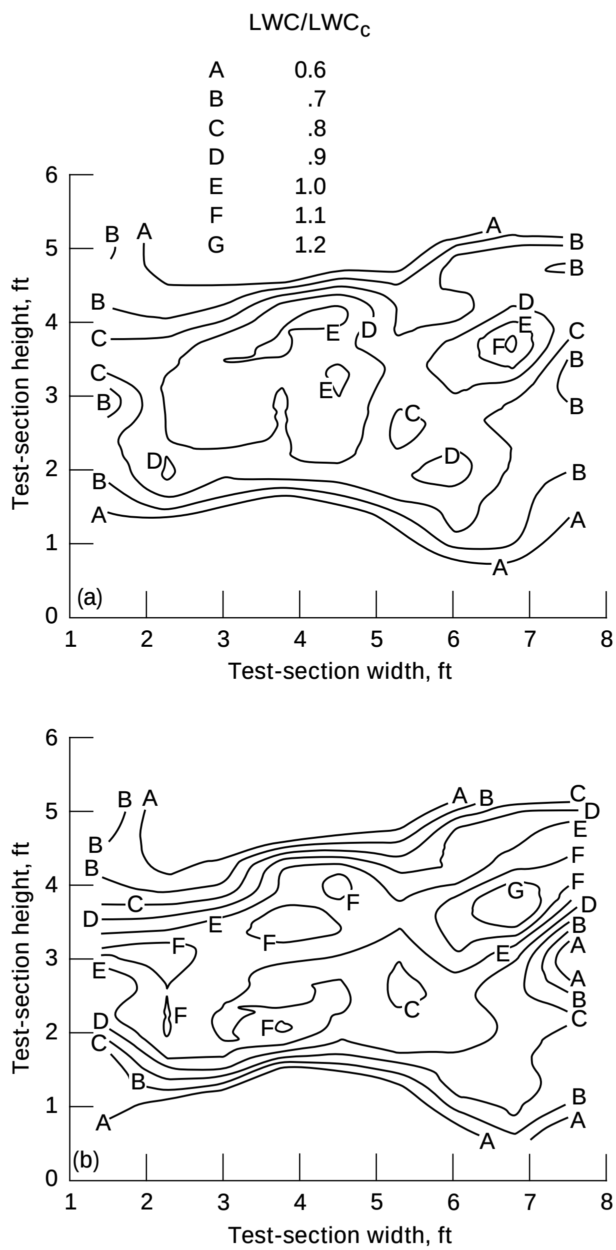
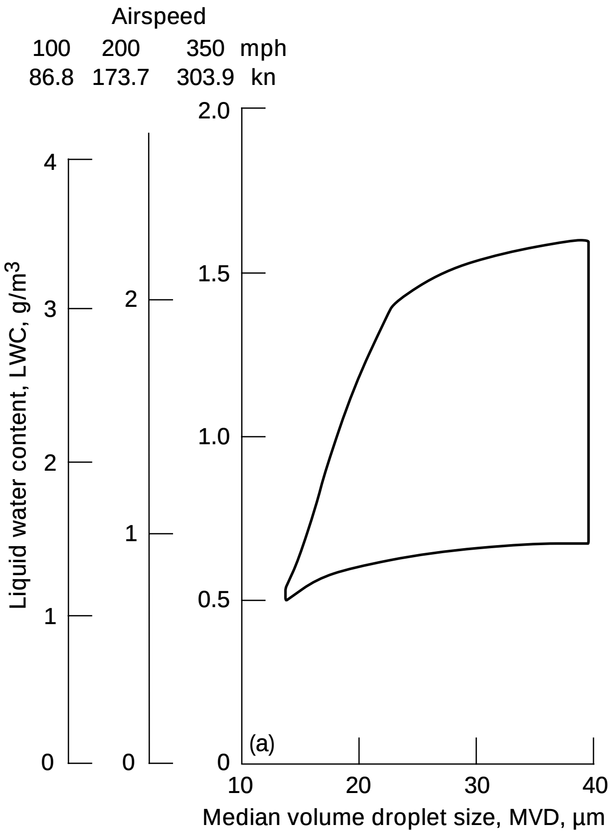


Figure 17.—Contour maps of liquid water content distribution in NASA Lewis IRT test section (airspeed 156.3 kn (180 mph)). (a) Standard nozzles. (b) Mod-1 nozzles.



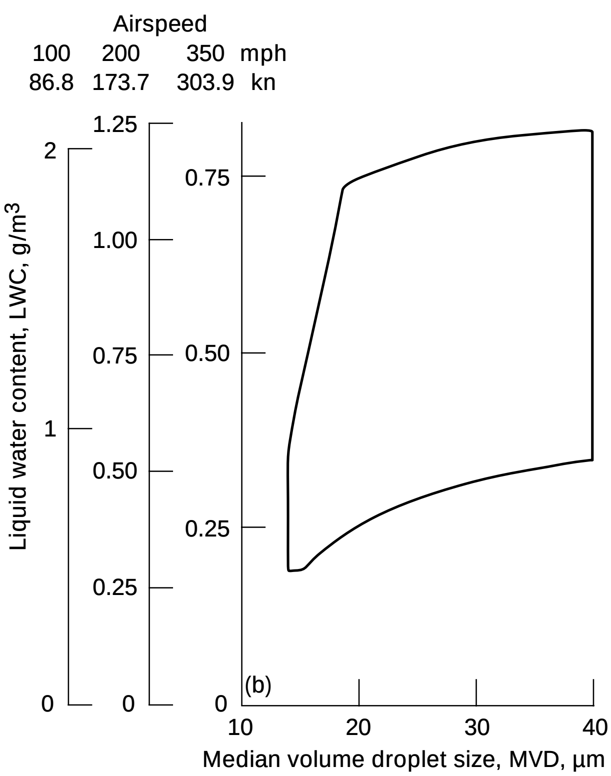


Figure 18.—IRT icing cloud operating envelopes for standard and mod-1 type nozzles. (a) Standard nozzles. (b) Mod-1 nozzles.

available on special request. Clouds can be produced with droplets as small as 9.5 µm and as large as 190 µm. The IRT project engineer should be consulted when special conditions outside of the normal range are required.

2.7 Control Rooms

There are two control rooms on the second floor of the balance chamber adjacent to the test section. A floor plan of the primary (tunnel-operation) control room, which is located south of the facility test section, is presented in figure 19. Models can be viewed from the control room through the observation windows shown on the floor plan and described in section 2.3. The secondary (tunnel-user) control room, which is located on the north side of the test section, is presented in figure 20. At one of the pretest meetings, the IRT project engineer and the IRT electrical engineer will describe the equipment and its location in the control rooms. The control rooms, the balance chamber, and the facility test section all are at the same static pressure, which is equivalent to an altitude of 8000 ft at the maximum tunnel velocity of 373.4 kn (430 mph).

The tunnel is operated from an interactive, distributive control system known as the Westinghouse Distributed Processing Family (WDPF). Two operator's consoles have color-graphic displays for setting and monitoring the facility's operation. From these consoles, tunnel fan speed, spray-bar air and water pressures, spray duration, turntable position, and other auxiliary systems are controlled. A third console contains instrumentation displays that are used to control tunnel lighting, fan low-speed lockout, and emergency shutdown.

The control room also contains the NASA Lewis Escort D data-acquisition system and the electronic scanning pressure (ESP) system for model instrumentation. The Escort D system is interactive (push-button) and can collect, process, display, and record data as accumulated during a test. Refer to **Data Acquisition** (sec. 5.1) for further details on the Escort D and ESP systems.

3.0 General Support Service Systems

The following information is provided to acquaint the tunnel user with support services that are available at the test section.

3.1 Heated Air Systems

If the model requires heated air, there is a gas burner outside of the tunnel for that purpose. Either 150-psig combustion air or 125-psig service air can be supplied to the burner. When the 150-psig air system is used, flow rates of up to 5 lb_m/sec at a temperature of 500 °F can be achieved. When the 125-psig air system is used, a flow rate of 0.1 lb_m/sec at a temperature up to 700 °F can be attained. The heated air is transported to the model through a 4-in.-diameter line that can be downsized to

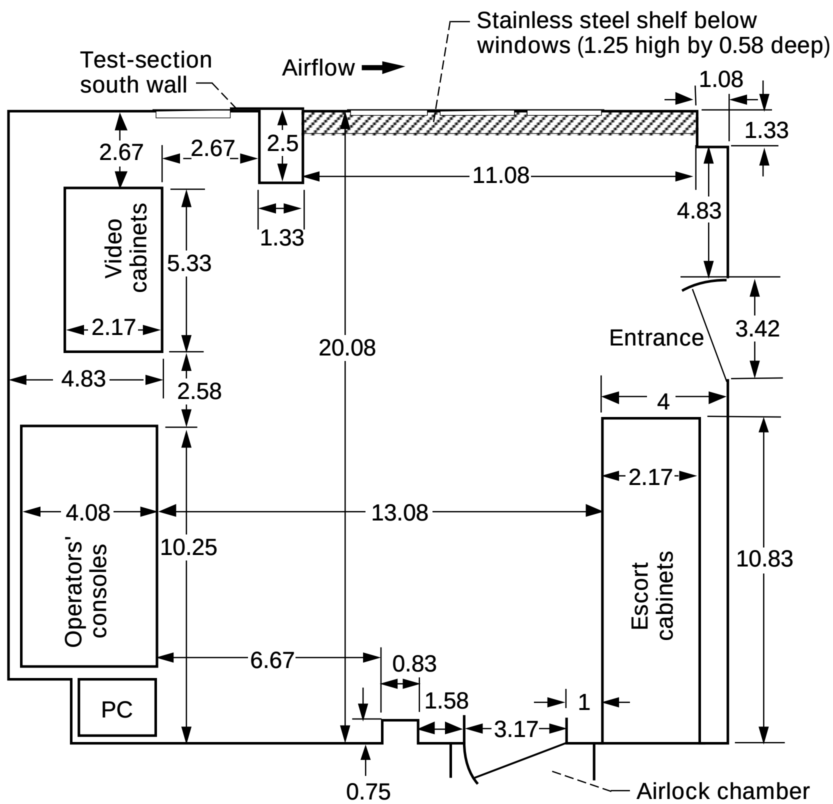


Figure 19.—Floor plan of IRT primary control room (all dimensions are given in feet).

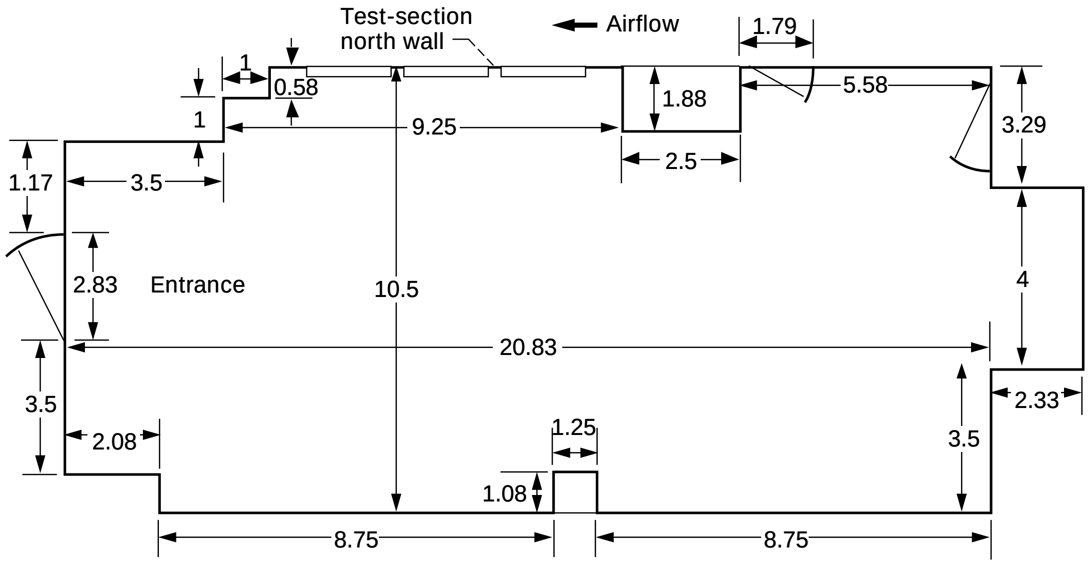


Figure 20.—Floor plan of IRT secondary (tunnel-user) control room (all dimensions are given in feet).

meet model requirements. In addition, there is a 2-in. supply line that tees off of the main 4-in. line and runs through a 45-kW, 440-V electric heater. The maximum heater output is 900 °F, with an associated maximum flow rate of 0.5 lb_m/sec. The gas burner and the electric heater can be used independently. However, when the gas burner and the electric heater are used simultaneously, the gas burner acts as the preheater. The IRT project engineer can discuss with the tunnel user the flow equations that are used to compute flow rate in the heated air system.

3.2 Steam and Service Air Systems

A 3/4-in.-diameter line provides 40-psig steam, which may be used for model and/or instrumentation deicing. In addition, a steam-heated, wedge-shaped tool and a slender, hollow rod are available to remove accreted ice from the model between test runs.

Service or shop air, nominally at 125 psig, is available for pneumatic tools that may be needed to install the model in the test section.

3.3 Altitude Exhaust System

Vacuum pumps that provide the altitude exhaust to the IRT are located in central facilities at NASA Lewis and, thus, are a shared resource which must be scheduled on a weekly basis. Requests for services are submitted on the Thursday prior to the test week.

The IRT altitude exhaust system is used to simulate flows for inlet models. It consists of a series of duct expansions and contractions that vary in diameter from 24 to 36 in. The relationship between the test-section turntable and the altitude exhaust piping is presented in figure 21. The flow rate of the system is measured by a venturi installed in the facility ducting. Three different sized venturis are available: one is calibrated for a 0.1- to 3-lb_m/sec flow rate, the second is calibrated for a 3- to 20-lb_m/sec flow rate, and the third is calibrated for a 15- to 85-lb_m/sec flow rate. The smallest diameter venturi is installed in a 12-in.-diameter pipeline that runs off of and parallel to a 36-in.-diameter pipeline. Either of the other two venturis can be installed directly in the 36-in.-diameter line.

The IRT project engineer can discuss with the tunnel user the flow equations that are used to compute altitude exhaust system flow rate. The flow is regulated by a pneumatic butterfly valve that is controlled by the facility computer. In each system the butterfly valve is upstream of the venturi.

3.4 Force-Balance System

The IRT houses an external force-balance system that can be installed to measure aerodynamic loads on the test model. Loads that can be measured are those acting in a horizontal plane on a model attached to the turntable in the floor of the test section. The model may also be attached to a support in the ceiling if additional strength and/or rigidity is required. The balance components mounted under the turntable form the lower platform balance, and those in the ceiling structure make up the upper bearing balance. Loads transmitted to the floor and ceiling attachments are measured and recorded independently; this allows users to analyze load reactions separately when a model is supported at both its upper and lower ends. Figures 22 to 24 provide details of the upper- and lower-attachment configurations.

Five load reactions can be measured with the IRT force-balance system: The lower platform balance can measure two force components on the floor mount, which are parallel to and normal to the horizontal centerline of the turntable, and one moment on the floor mount about the vertical centerline of the turntable; and the upper bearing balance can measure two force components on the upper mount, parallel to and normal to (a projection onto the ceiling of) the horizontal centerline of the turntable. Since the model is free to rotate about the vertical centerline of the turntable in the upper bearing balance, there is no moment reaction at the upper mount. As the turntable is rotated to produce different angles of attack on the model, the directions of the measured loads also rotate, remaining parallel and normal to the turntable centerline.

For example, if an airfoil model is mounted in the test section with its span vertical and its chord parallel to the test-section longitudinal centerline, the balance system can measure not only the normal and chordwise reaction forces independently at the lower and upper ends of the airfoil, but also the pitch moment on the airfoil at its lower end. Table I lists the load capacities on the total balance system in the normal, chordwise, and pitching directions for the two methods available for mounting test models: (1) a model attached to the lower balance only, and (2) a model attached to both the lower and upper balances.

The full-scale ranges of individual load cells within the balance system can be selected to provide the required sensitivity to the user's expected loads, within the total capacities listed in table I. All load-cell output signals are collected through the Escort D data system for online and/or postprocessing analysis. The IRT project engineer is available to answer any questions that the tunnel user may have regarding installation of the model and the force balance.

3.5 Model Electrical Power

The descriptions and maximum capacities of the power systems available to the tunnel user are listed in table II.

3.6 Facility Data-Recording Equipment

To record research data, IRT customers may use the 10-track visicorder. The IRT electrical engineer is familiar with the visicorder and can assist customers in using this equipment. In

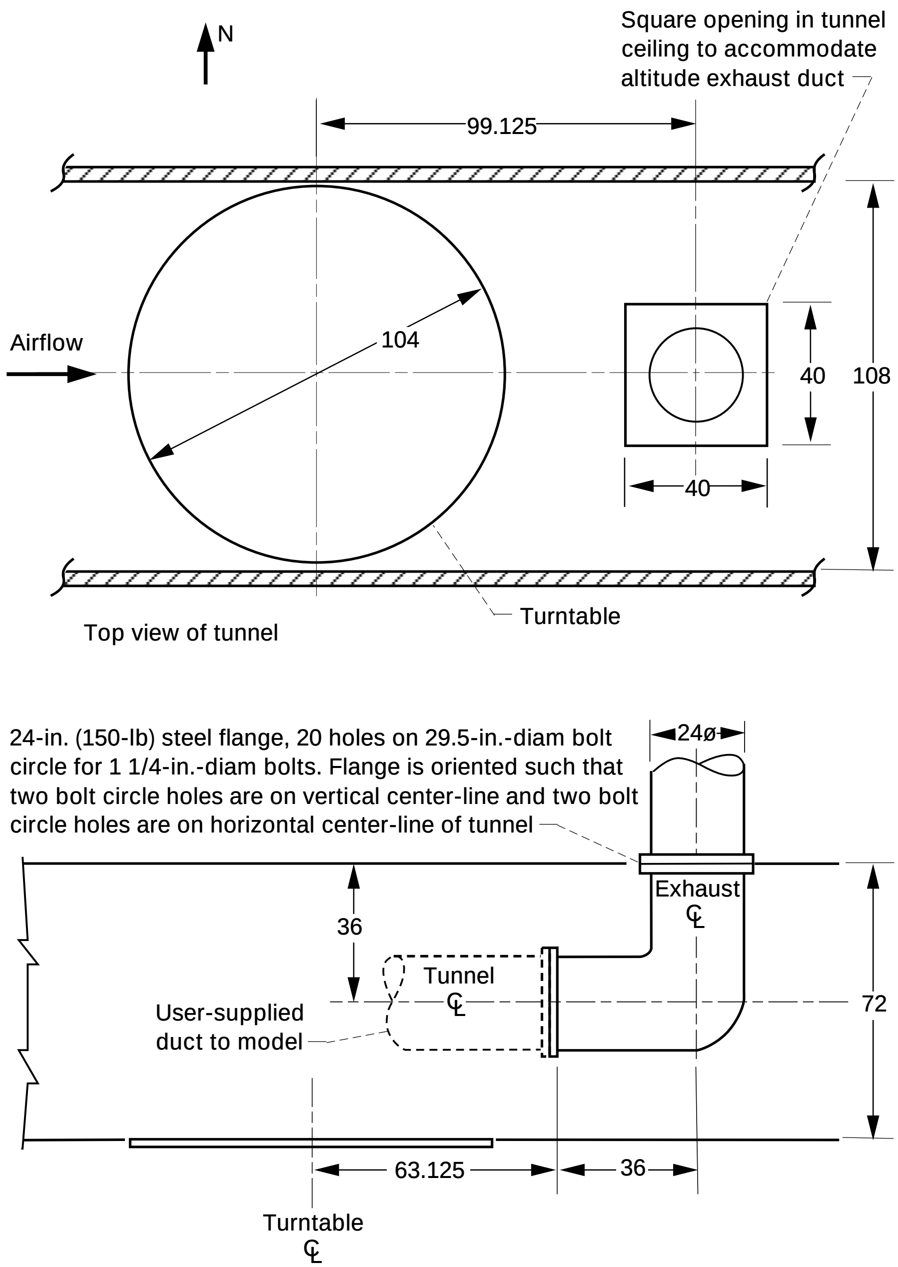


Figure 21.—Schematic of IRT test section showing location of 24-in. standard steel flange and elbow (altitude exhaust inlet) (all dimensions are given in inches).

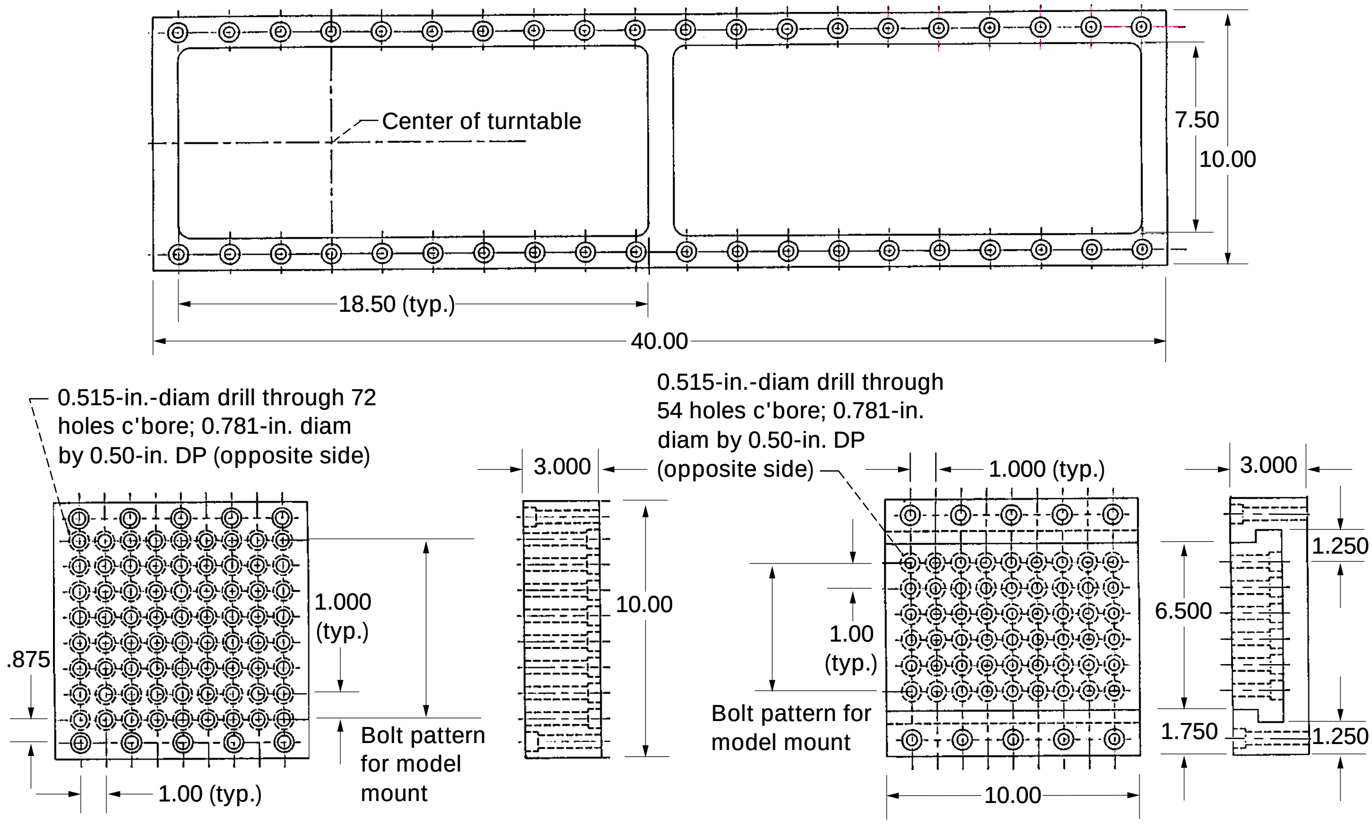


Figure 22.—IRT force-balance lower model mount (all dimensions are given in inches; typ. = typical).

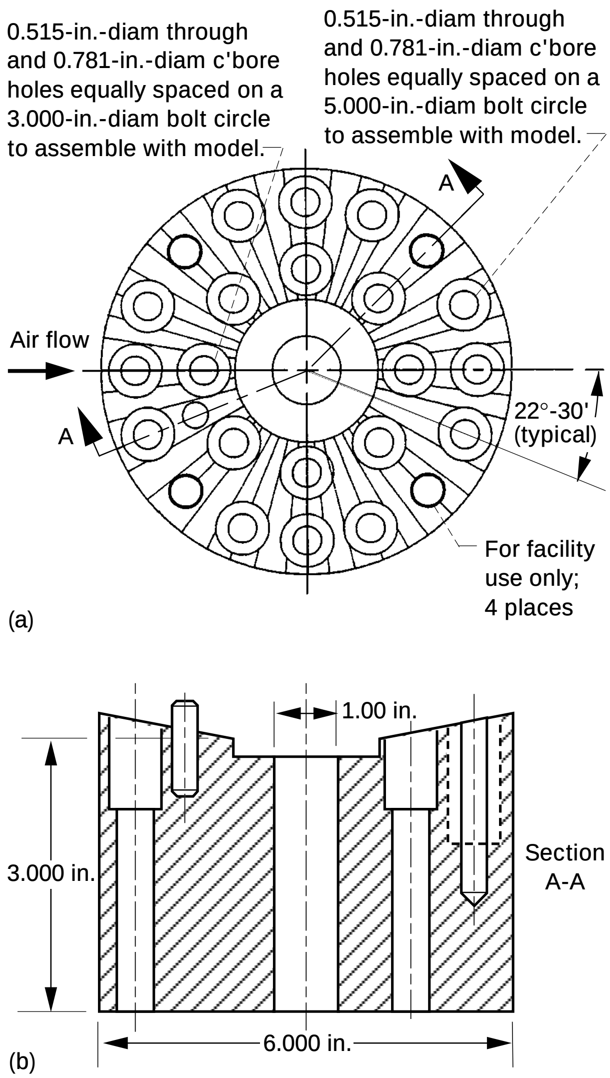


Figure 23.—IRT force-balance upper model mount.
(a) Top view. (b) Side view.

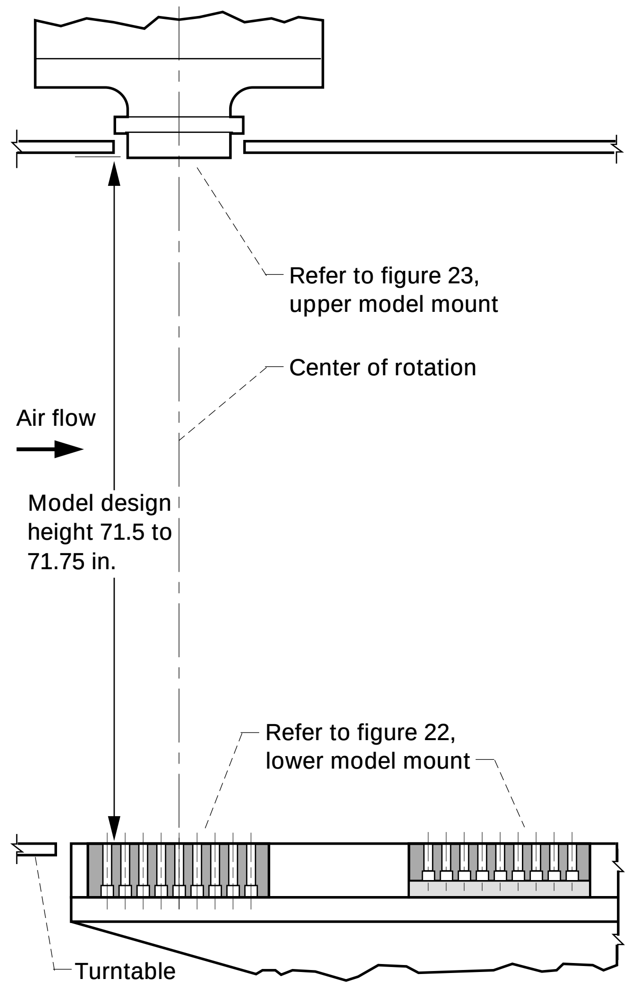


Figure 24.—IRT force-balance mounting pads (side view).

TABLE I.—CAPACITIES OF THE IRT FORCE-BALANCE SYSTEM FOR TWO MODEL-MOUNTING METHODS

Load component	Capacity of mounting method	
	Lower mount	Lower and upper mount combined
Force, lb_f		
Normal Chordwise	±10 000 ±1 000	±20 000 ±2 000
Moment, ft-lb_f		
Pitch moment	±10 000	±20 000

TABLE II.—MAXIMUM CAPACITIES OF POWER SYSTEMS

Voltage, V	Frequency, Hz	Current, A
Three phase		
440	650	[a]440
[b]208	60	225
120/208	[c]400	[d]175
Single phase		
115	600	250
115	400	30
26	400	15
[e]28 dc	– –	250
28	– –	25

[a]Amperage depends on other auxiliary systems that may be in use. This 440-V system supports the four electrically heated test-section windows in the south control room and the three electrically heated windows in the north control room (sec. 2.3) at 15 A each; the electric air heater (sec. 3.1) at 100 A; a 28-V dc inverter at 30 A; and a 115-V, 400-Hz converter at 130 A.

[b]Can be used as single-phase 208-V system or single-phase 110-V system.

[c]System is 400 V, 60 Hz converted to 208 V, 400 Hz; 15-kW capacity on motor generator.

[d]If generator used at another AFED facility is available, then 175 A can be provided for IRT test.

[e]440-V, 60-Hz to 28-V dc inverter.

addition to the visicorder, tunnel users have access to six Panasonic industrial S-VHS video tape recorders (VTR's) for use with the photographic equipment described in section 4.4. These VTR's provide over 400 lines of horizontal resolution in the S-VHS mode because of the increased bandwidth of the format's luminance channel (1.6 MHZ). Additional features of the VTR's are discussed in reference 9. The IRT project engineer can also direct tunnel users to a member of the Imaging Technology Center at NASA Lewis to obtain more detailed information on this equipment.

4.0 Instrumentation

Instrumentation in the IRT may be categorized as (1) facility instrumentation or (2) model instrumentation. The facility instrumentation necessary to operate the tunnel is normally displayed on the WDPF graphic pages. Data such as tunnel velocity, motor revolutions per minute, average tunnel temperature, model angle-of-attack, spray-bar control parameters, and other auxiliary systems information are primarily monitored by the tunnel operators. Hard copies of display pages showing the values of these parameters are available on request. In addition, most of the facility instrumentation is duplicated and available at the patchboard of the Escort D data-acquisition system. These parameters can be included in the scan pattern of specific data software modules and, thus, be recorded as part of the overall test plan.

Model instrumentation is handled by the Escort D data-acquisition system, which has a capability of 192 analog input channels. In the standard software module, 92 channels are reserved for facility instrumentation, thereby leaving 100 user-defined channels for the model. If all 92 channels are not needed, the remainder can be repatched and used for model data. Any combination of temperatures, strain gauge pressures, flowmeters, load-cell deflections, or in general, voltage source signals (10-V dc maximum) can be assigned to these channels. Twenty signal conditioners are readily accessible if needed for any of the Escort inputs.

Special model pressures that must be read numerous times and/or must be highly accurate are measured with the ESP system. This system can read 192 model pressures (with 186 data channels and 6 check pressure channels), and it can be tied into the Escort D data system. These channels are in addition to the 192 analog input channels previously noted.

All data going to the Escort D system can be permanently recorded on a data collector for further offline processing. An option to preserve data on magnetic tape for future reduction by the tunnel user can be exercised at the completion of the test. Specific details of the Escort D and ESP systems are given in **Data Acquisition** (see sec. 5.1).

4.1 Temperature Measurements

Facility temperatures are measured at all four corners of the tunnel. Corner D of the tunnel (see fig. 2) has 11 type-T thermocouples whose readings are mathematically averaged to represent the air temperature in the test section. Each spray bar is also instrumented with thermocouples to measure both air and water temperatures. These facility temperatures are displayed on the WDPF system. The thermocouple measurements have an uncertainty limit of ±1.6 °F.

The preferred method of measuring model temperatures is to use the 48 type-T copper-Constantan thermocouples that reside in existing interconnect boxes. The interconnects can be accessed from the top hatch of the test section or through the floor of the test section underneath the turntable. Full size, three-prong male connectors are needed to fit into the interconnects. An additional 96 thermocouples can be accommodated by two 48-channel, 150 °F reference ovens. These ovens can be accessed only from the bottom of the test section. Oven inputs require no connectors and handle type K-, T-, J-, or E-thermocouples.

4.2 Pressure Measurements

The two facility pitot tubes measure total pressure with a 0- to 15-psia transducer and measure total-minus-static pressure with a 0- to 3.0-psi differential pressure transducer. These pressure measurements are input to the WDPF and the Escort D systems and, together with the test-section temperature, are used to calculate the tunnel velocity. Manufacturer error specifications on these transducers are ±0.14 percent of full scale. The equation used to compute the test-section velocity is available from the IRT facility electrical engineer.

The facility spray-bar air pressure and water-minus-air differential pressure are displayed on the WDPF and the Escort D data systems. The air pressures are held to within ±0.1 psig, and the pressure differences are held to within ±2 percent or ±2 psid (whichever is greater) of their respective setpoint values in the steady-state spray mode. There are six 32-port ESP modules for measuring model pressures. Port 1 of each module is reserved for check pressures, which leaves a balance of 186 channels useable for research measurements. Each channel has its own transducer, with accuracy specified as ±0.1 percent of full scale (i.e., ±5 psid).

4.3 Model Attitude

A model mounted on the test-section turntable can be rotated ±20° about the test-section vertical centerline. Angular data can be recorded on the WDPF and the Escort D systems; the accuracy of this measurement is ±0.1°. Turntable rotation in excess of ±20° can be accommodated to meet tunnel-user demands. This point should be discussed with the IRT project engineer.

4.4 Photographic Documentation

Video and still photographic equipment may be used to record visual data and to document instrumentation. The cameras available for use in the IRT are discussed in reference 9. Photographic equipment may be mounted in or on the tunnel hatch or in the control-room windows (see fig. 12 for arrangement of panels in the hatch cover); such equipment may also be carried into the test section between runs. If necessary, the acrylic windows can be replaced with other materials (see sec. 2.3). Alterations to the hatch cover need to be discussed with the facility manager as far in advance of the test as is possible. Tunnel users must supply their own film and video tapes.

Imaging support is available from the Imaging Technology Center. The Still Photo Imaging Group can provide documentation of hardware, installation, or other aspects of the test. The Scientific Imaging Group specializes in using a variety of imaging technologies as problem-solving tools for data acquisition and analysis. They can give technical assistance and advice for more complicated needs. The Imaging Technology Center recommends that imaging requirements be discussed as early in the project planning as possible to ensure the availability of systems and support.

In the following paragraphs (1) still imaging, (2) video imaging, (3) high-speed imaging, and (4) digital still imaging are discussed.

4.4.1 Still imaging.—The IRT facility has both Nikon F3 and F4 cameras available with standard databack and flash equipment. Exposure time of the Nikon F4 can be as fast as 1/8000 sec, and the continuous motor drive rate is 5 frames/sec.

Depending on the needs of the test, the ambient lighting in the tunnel may be supplied by quartz halogen lamps with a color temperature of 3200 K or HMI lighting (hydrargyrum medium-arc-length iodide lamps) with a color temperature of approximately 5500 K (daylight). In most circumstances, flash is recommended.

The focal lengths of available Nikon lenses range from 35 to 400 mm. The 60-mm macrolens has been the most popular both for general overall shots and for closeups of icing details.

4.4.2 Video imaging.—Several video cameras are available to IRT customers. There are cameras for both black and white and color imaging. They all operate at the standard rate of 30 frames/sec and take “C-mount” lenses; however, adapters are available that allow Nikon lenses to be used as well. The camera signals can be genlocked (video signals synchronized) if necessary.

All video camera control units, pan and tilt controls, video tape recorders, switching units, and monitors have been installed in rack-mounted cabinets in the IRT control room. There are eight 3.5-in. status monitors that can be used to display the signals from eight video cameras. Video signals from six of these eight monitors can be sent to six 8-in. monitors. Six video recording decks associated with these monitors can record in the S-VHS or regular VHS format. A switching mechanism associated with a 13-in. monitor located in the rack is used to select one of the six displays from the 8-in. monitor. All video signals can have a time code inserted, which is a help in comparing different views or tapes of the same event. There is also a character generator for inserting text into the video. It has been used to add titles to different views, to simply name a test, or to annotate run conditions. Finally, a Sony Still Video Printer is available for capturing still frames and for printing. A switcher can divert any video signal into it.

One of the video cameras is a Panasonic D5000 color camera. It is mounted in the well above the test section so that it can monitor the model for safety. If the user so desires, the output of this camera can be recorded for use as data. Additional cameras include high-resolution Sony AVC-D7’s, which are small black and white cameras that, depending on lighting, can be gated down to 1/10 000 sec. Wiring that allows these cameras to be placed in any test-section window already exists. Sony DXC-101 and DXC-107 color cameras are also available, and like the AVC-D7’s, they too can be placed in any window.

They do, however, have a lower resolution. Finally, a Xybion camera, which has both extremely short duration gating capabilities (10 nsec) and low-light sensitivity, is available. Additional information on these cameras can be found in reference 9.

4.4.3 High-speed imaging system.—For high-speed imaging, the IRT has two different Kodak Ektapro Motion Analysis systems. Both employ intensified imagers capable of being gated to 10 μsec and operating at 1000 frames/sec. Their resolution is lower than that of conventional video.

Both systems consist of an imager, its controller, and the processing unit. However, there are significant differences between the two: With the Ektapro TR system the data are recorded on special tapes, synchronization with the event is crucial, and the total recording time available at 1000 frames/sec is 30 sec; with the Ektapro EM system the images are stored in electronic memory, synchronization with the event is less critical because the EM has a post-trigger mode, and the recording window at 1000 frames/sec is 4.9 sec.

The images captured by either system must be downloaded to a video cassette recorder (VCR) if the information is to be saved. If desired, single frames can be directed to the video printer. Another option is to have frames stored and analyzed by a computer. Assistance from a member of the Scientific Imaging Group is necessary to set up and operate the Ektapro and its components.

4.4.4 Digital camera.—Facility customers may use a Kodak Professional DCS 420 digital camera during IRT experiments. The system consists of a Nikon N-90 body and a special Kodak back. The DCS 420 can be used to capture single frames or a sequence of up to five images at a rate of about 2 frames/sec. All of the camera's functions can be used with the DCS 420: self-timer, different flash modes, and different light-metering options. The images can be stored in the memory unit of the DCS 420 or on a Personal Computer Memory Card International Association (PCMIA) type-III card. With the latter option, either commercially available hard disk cards or flash memory cards are used for storing the images.

The digital images produced by the Kodak DCS 420 have a resolution of 1524 × 1012 pixels with 36-bit color (12 bits/channel—red, blue, and green). The DCS system is powered by batteries that can capture up to 1000 images per full charge. An alternating current battery charger/adapter is included with the system. The images can be transferred from the DCS to a host computer by inserting the memory unit or hard disk card into the host computer and connecting it either to a DOS-based computer that supports Microsoft Windows, or to a Macintosh. In this mode the camera serves as the card reader.

4.5 Standard Flow Visualization Techniques

Common techniques to facilitate flow visualization, such as coating the model with fluids or chemicals or employing optical methods, may be used in the IRT. Coating the model with a viscous fluid or paste, or spraying the model with a fluorescent oil before a test run is permitted; however, such model preparations must be done by the tunnel user.

Any chemicals used to produce a visual effect in the tunnel must be nontoxic to personnel and must be noncorrosive to the facility. Documentation attesting to the benign nature of the chemical is required. Optical devices may be mounted in the test-section hatch cover, but they must be supplied by the tunnel user.

4.6 Laser Sheet Flow Visualization

The laser sheets used in the IRT facility are produced by a 15-W, argon-ion laser. The laser and an attached optical box are placed on a laser table that is located on the third floor of the IRT balance chamber. Since the balance chamber may experience drops in pressure of up to 2 psia, the laser is housed in an environmentally controlled box that keeps the laser tube at a constant pressure. The optical box that is attached to the laser is made of Gentex wavelength-limiting Plexiglas, which allows the observers to see the optical components inside the box; the laser beams, which operate in the 460- to 540-nm wavelength, cannot be seen. Fiber-optic cables from the optics box extend to a laser-sheet-generating optic head that is located on a traverse mechanism mounted to the overhead hatch of the IRT test section. The lenses in the optical head produce a vertical sheet of light that can be positioned along the longitudinal centerline of the test section in order to study the flow at various longitudinal locations of the model.

The flow field can be viewed by using three video cameras. One camera, located on the hatch (which is on the third floor of the facility balance chamber) permits an overhead view of the laser sheet. A second video camera, located in the auxiliary control room, permits a side view of the laser sheet. And a third video camera, placed upstream of the model, permits a frontal view. Questions about the positioning of the video cameras can be discussed with the IRT project engineer and the facility electrical engineer.

During testing, the windows in the primary control room are covered with Gentex wavelength-limiting Plexiglas to block the laser light from the tunnel operators and the tunnel users. These windows make wearing safety goggles in the primary control room unnecessary; therefore control-room operations, including observation of the model, can continue as usual.

4.7 Infrared Thermography System

The IRT has an AGEMA infrared system for tunnel users who require thermal measurements and analyses. The infrared system has two different lenses, with fields of view of 20° or 40°, respectively. The lens that is used for a test is coupled to a scanner module with two built-in temperature references (microblackbodies). The scanner's accuracy is ±1.8 °F, and its sensitivity is 0.18 °F at 86 °F. Optical stability is achieved through precision, diamond-turned optics, and mechanical stability is achieved by housing all optical components in a single structural element.

The signal is digitized in the system scanner prior to being delivered to the system controller. This feature eliminates the risk of data corruption normally associated with analog systems. The 12-bit data acquisition and storage ensures that all information required for full-image analysis is obtained and retained, regardless of the system settings at the time that measurements are taken. The system scanner is coupled to the system monitor, keyboard, and mouse. The monitor, in turn, is coupled to the system controller and video printer.

Data acquired by the system scanner are transferred to the system controller, which contains a built-in local area network (LAN) interface through which the images can be transferred to a personal computer (PC) or other workstation for further analysis or archiving.

The lens and scanner are portable and, thus, may be placed at various locations throughout the test section of the tunnel. The system is remotely controlled from the north control room. Tunnel users should indicate the need for this equipment as early as possible, because it is occasionally loaned out to other facilities.

5.0 Data Processing

5.1 Data Acquisition

At present Escort D, which is supported by the NASA Lewis Computer Services Division (CSD), is the facility data-acquisition and display system. This system is flexible enough to accommodate changes in the experiment and can also be a node in a large, distributed network system or a stand-alone computer data system. It offers high resolution and fast update rates for cathode ray tube (CRT) displays. Escort D is a minicomputer-based, real-time, data-acquisition and display system. It is generally applicable to steady-state tests and, in some cases, "slow" transient tests with periods of 1 sec or more. The Escort D system contains a superplex data-acquisition feature that permits sampling of a subset of data channels at a faster rate than the basic update rate. The subset of data channels is sampled repeatedly at specified time intervals, all within one scan of the data. This repeated scan (the subset) is referred to as the fast scan; the nonrepeated part of the entire scan is called the regular scan. Typically, the superplex data-acquisition feature is applied with moving probe data. The moving probe is placed downstream of the model to sample the flow field across the test section.

Analog data from an experiment are digitized and then acquired by a minicomputer located in the IRT control room. These data are then transmitted through a network link (for unclassified projects) to a data collector in the Research Analysis Center (RAC). Data from sensitive projects are stored on the control-room minicomputer. Real-time processing tasks include scheduling a data-acquisition cycle, converting raw counts to engineering units, performing online calculations, updating the facility display lists, and formatting the data for archival recording on a data collector. The minicomputer also distributes the processed data to the various displays and output devices in the control room. Figure 25 shows the flow of information schematically. Communication takes place over an Ethernet data link; update time for a standard-length program display is 1 sec. Data can be acquired and processed with a standard data software module or one specifically designed for a particular task.

Tunnel users have the option of furnishing their own data-acquisition and data-processing equipment or providing model instrumentation that is compatible with the Escort D system. Data-acquisition needs should be specified during a pretest meeting between the tunnel user, the IRT facility manager, the IRT project engineer, and the IRT electrical engineer.

5.1.1 Types of instrumentation.—Thermocouples, pressure transducers, or any other analog voltage signal devices (10-V dc maximum) are compatible with the Escort D system. Turbine-type flowmeters with frequency outputs are handled by using frequency-to-direct-current converters.

5.1.2 Electronically scanned pressure (ESP) system.—Steady-state model pressures that must be highly accurate and/or must be read repeatedly are usually measured with the ESP system. This system uses plug-in modules, each containing 32 individual pressure transducers that can be addressed and scanned at a rate of 10 000 ports/sec. The standard calibration interval of all ESP transducers is every 400 cycles (approximately every 15 min), but the time interval can be varied if required. A unique feature of the ESP system is its ability to apply a three-point pressure calibration to all port transducers. The three calibration pressures are measured with precision digital quartz transducers. The online calibration of all port transducers ensures that errors are not greater than ±0.10 percent of full scale.

The IRT has six 32-port (±5 psid) ESP modules, for a total of 192 pressure channels (1 port/module is used for a check pressure, which leaves 31 channels/module or a total of 186 channels for test data). An online graphic display of each channel is programmed into a PC. Each cycle of pressure readings can also be digitally displayed when a prompt appears on the screen. A continuous cyclic update can be digitally displayed by linking the ESP system to the Escort D data system.

5.1.3 Real-time displays.—The standard general-purpose Escort D program uses 192 channels, which are displayed in real time as pages on a monitor in the control room. Page 1 of the output is an overall display directory. The next page lists output for data channels 1 to 100 in an unlabeled (i.e., no text description) block format consisting of a two-dimensional array of 10 rows and 10 columns. Data channels 101 to 192 are listed on page 3, and the following parameters are listed on page 4: pitot tube pressures, air temperature, density, viscosity,

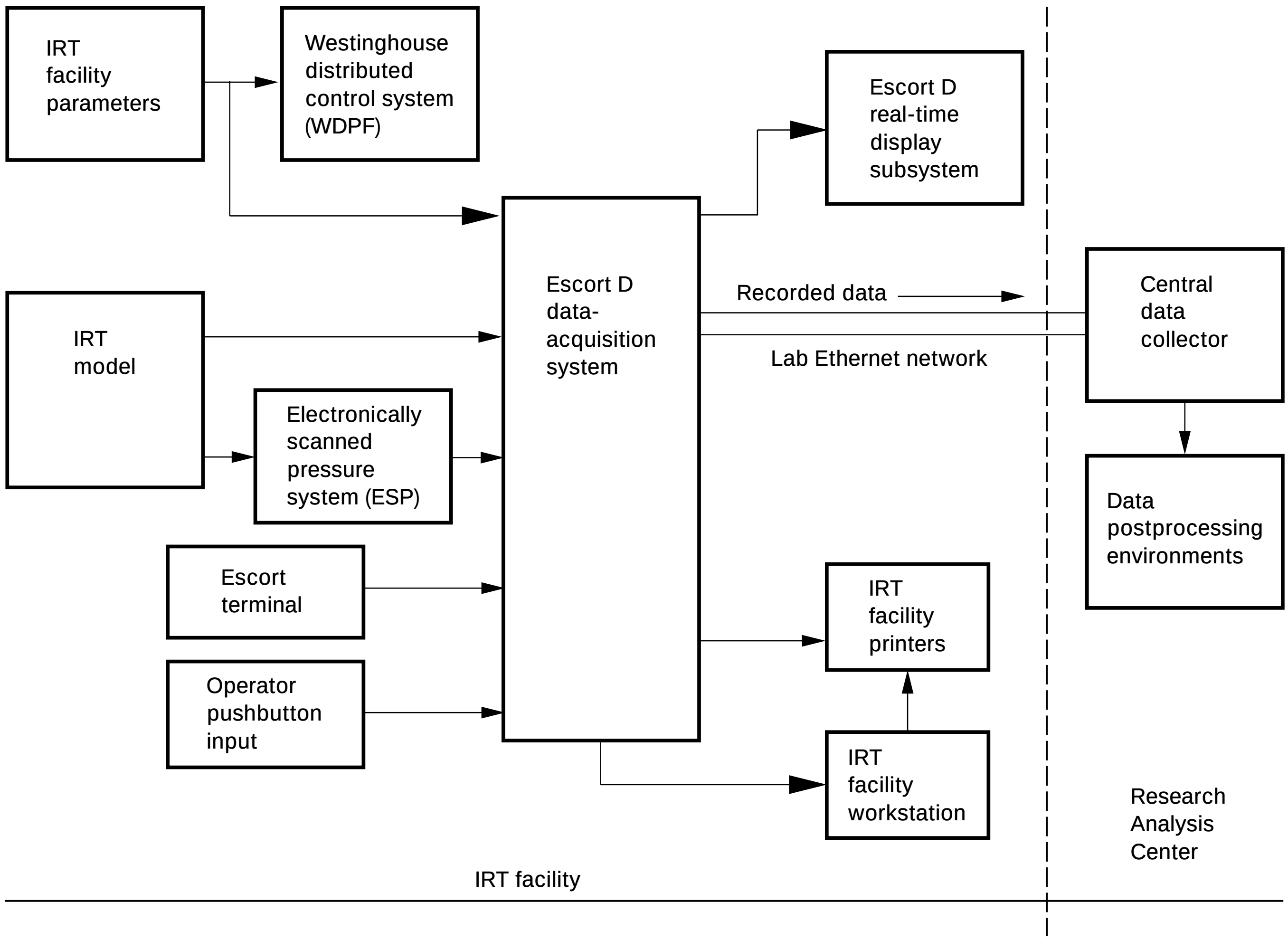


Figure 25.—IRT data system.

balance-chamber pressure, and turntable position. In addition, there are computed values for test airspeed, Mach number, and Reynolds number. Page 5 of the output contains the following tunnel circuit parameters: corners C and D temperatures, spray-bar air pressures, and spray-bar water-air pressure differentials. Each display is updated every 1 or 2 sec.

Nonstandard Escort D outputs are possible, but such outputs would require additional editing. Requests for nonstandard Escort D output should be presented by the tunnel user to the project engineer as part of a computer requirements package 8 weeks before the start of the test program. The IRT project engineer will set up the necessary meeting with CSD personnel to discuss these computer requirements.

5.2 Data Collection

When the standard data software module is installed on the Escort D system and the *Data Record* button is activated, all data channels are scanned once, saved on the data collector, and assigned a unique reading number. Data can be processed offline by using the Center's mainframe computer to provide the desired output. The user can press the *Data Record* button as often as required to collect a new cycle of data. If multiple high-speed scan cycles are needed to define a test condition, a customized data software module must be created for and used on the Escort D system. Then, activating the *Data Record* button would result in automatic multicyclic scanning per reading, as defined in the customized module. Multicyclic data gathering is usually applied to "slow" transient tests.

5.2.1 Standard output.—The printed output from the standard data-reduction program is identical in format to the CRT display pages (see sec. 5.1.3), except that pages 2 and 3 are combined into one page listing the 192 channels. Currently there are no output plots defined for the standard data-reduction program.

5.2.2 Nonstandard output.—The format for output from a nonstandard data-reduction program is developed for each specific test. Customized data plots, calculations, or specific data printouts can be obtained by either online or offline batch processing. Online real-time plotting is also available. These specialized outputs from a facility or mainframe computer can be developed if at least 8 weeks of lead time is allowed for programming.

An example of a customized data-reduction program was the wake survey probe, in which a movable pitot-static probe traversed the tunnel test section behind a model. Pitot-static tube pressures were recorded in the superplex data-acquisition mode (see sec. 5.1). These data were then processed offline to provide plots of pressure as a function of traversed distance, of velocity profiles behind the model, and of computed pressure differences and velocity ratios across the model. Drag coefficients were also calculated.

5.3 Facility Workstation

The IRT south control room (see fig. 2) contains a Silicon Graphics Model 4D Indigo workstation currently running IRIX 5.2 System V. This workstation consists of a monitor, chassis, keyboard, mouse, and power and monitor cables. The workstation is generally used by facility customers for online processing and postprocessing of test data that has been transferred from the Escort D system.

Customers need a user identification number (userid) to access this workstation. To obtain one, contact the IRT facility electrical engineer, who will review the request and forward it to the system administrator in the Propulsion Systems Division. Questions about the system, (e.g., available storage, general packages available, etc.) can be directed to the system administrator.

Tunnel users interested in processing Escort D data locally on this workstation may wish to use the CEDARS software. It was developed initially for postprocessing sensitive data on stand-alone systems, but now it is configured to process data transferred in real time from the Escort D system. CEDARS has a general-processing capability with many of the same functions as are available on the mainframe system. It provides full-service data reduction, including storage of the data in a data base that is portable and maintainable on any file server. The primary element of CEDARS is a graphical interface supported by PV-Wave, a set of programs that integrates processed data with plot specifications in interactive and batch mode. Programming support is provided by the Scientific Data Systems and Applications Branch within CSD. If the tunnel user requires programming support, the equation sets should be given to the IRT project engineer 8 weeks before the start of testing in the IRT. The IRT project engineer will arrange for a meeting between the tunnel user and the CSD software representative.

For secure processing, CEDARS software and any other packages used must be downloaded and stored locally with the data. A 4-mm, 2.0-GB tape drive is available for backing up and offloading the data. A floppy disk drive is also attached for tunnel users who wish to transfer the data to a PC. There is a networked PostScript printer in the IRT facility, but it must be shared with the Escort D system during facility testing. This printer can also be disconnected from the network for use during sensitive testing.

6.0 Pretest Requirements

NASA Lewis schedules the IRT for continuous testing throughout the year. It is advisable to contact the IRT facility manager (see appendix A) at least 1 yr in advance of your desired tunnel test time. Early notification will allow the facility manager and the appropriate IRT personnel to review the proposed model design and to ensure compatibility with the tunnel test section. Non-NASA users should send a formal request for tunnel use to the IRT facility manager at NASA Lewis. Include the following pertinent information in the formal letter of request: (1) a brief description of and the purpose of the test, (2) the NASA Lewis point-of-contact, if any, and (3) a request for test time, including the approximate dates and duration.

The address of the IRT facility manager is presented in appendix A. On receipt of a formal request for tunnel test time, the IRT facility manager will review the project. If the project is accepted, a test agreement will be prepared and sent to the requester to be signed (non-NASA requesters only). The test agreement outlines the legal responsibilities of both NASA Lewis and the tunnel user during the time the project is at the Center (model arrival, test time, model return, and so forth). The tunnel user should sign the test agreement and return it to NASA Lewis.

The four types of test agreements are as follows:

(1) NASA test program
(2) NASA/industry cooperative program (nonreimbursable Space Act agreement)
(3) Other U.S. Government agency agreement programs (reimbursable or nonreimbursable interagency agreement)
(4) Industry proprietary or noncooperative program (reimbursable Space Act agreement)

The tunnel user is also requested to prepare a systems report for the model (see ref. 10, sec. 6.1) and make it available to the IRT facility manager and the IRT project engineer at the first pretest meeting held at NASA Lewis. The AFED project engineer noted in reference 10 is analogous to the IRT project engineer in this report, so their duties are the same. A summary of the procedure to obtain tunnel test time is contained in appendix B.

6.1 Pretest Meetings

A series of pretest meetings are held at NASA Lewis to discuss the test plan, instrumentation, tunnel hardware, data requirements, power requirements, and other miscellaneous services described in the following paragraphs. The number of pretest meetings held are usually a function of the complexity of the test. The attendees at these meetings are the requester personnel (e.g., the lead engineer plus key test personnel), the IRT facility manager, the IRT project engineer, appropriate AFED managers, and key IRT personnel.

6.1.1 Test objectives and run schedule.—The requester should provide a statement indicating the test objectives and goals. The statement should thoroughly explain any special test procedures. A prioritized run schedule compatible with the available test window should also be provided.

6.1.2 Instrumentation.—The tunnel user should provide the IRT project engineer with a list of requested instrumentation. If the Escort D data system is to be used, the tunnel-user's instrumentation must be adapted to the IRT data system (see secs. 4.0 and 5.0). If the tunnel-user's data system is to be used, this should be discussed with the IRT project engineer and the IRT electrical engineer at the first pretest meeting.

6.1.3 Hardware.—The tunnel user is required to submit drawings of the model installed in the test section. The tunnel user also must provide the mounting plate to attach the model to the test-section turntable (see sec. 2.3) and any other hardware necessary to fasten the model to the tunnel.

6.1.4 Data acquisition and reduction.—Data-reduction information, consisting of data inputs, data outputs, and equations in engineering language, must be provided if NASA Lewis is to reduce the data for the tunnel user. The IRT project engineer will contact the appropriate personnel in the CSD and set up any necessary meetings between tunnel users and CSD personnel to establish computing requirements. Final computing instructions are due from the tunnel user to CSD personnel 8 weeks before the start of testing.

Tunnel users may choose to bring a self-contained computer system onsite for data processing. Arrangements for this can be discussed with the IRT project engineer and the IRT electrical engineer.

6.1.5 Power requirements.—The power requirements for the model should be stated by the tunnel user at the pretest meeting. The power available is discussed in section 3.5.

6.1.6 Services required.—At the pretest meeting, tunnel users should specify which facility services will be required for their tests. The services available are heated air (sec. 3.1), altitude exhaust (sec. 3.3), and model attitude or turntable positioning (sec. 4.3).

6.2 Deliverables

The tunnel user must supply the IRT facility manager with the following information at least 8 weeks before the scheduled tunnel test:

(1) Test matrix for the model
(2) Loading on the model as related to Mach number, dynamic pressure, and model attitude (see ref. 10, sec. 6.1.2, which is part of the Model Systems Report)
(3) Stress analysis based on maximum anticipated loads on all sections (see ref. 10, sec. 6.1.3, which is part of the Model Systems Report)
(4) Detail drawings of the cross-sectional area distribution of the model to allow blockage and airload calculations
(5) Drawings that show the model installation and model support systems (see ref. 10, sec. 6.1.1, which is part of the Model Systems Report)
(6) All calibration information that is required of the tunnel user
(7) A list of all tunnel-user-supplied equipment, with block diagrams and wiring schematics of the equipment

If a model is identical or similar to a previously installed model/test, and if the test matrix does not exceed that of the previous test, the requirement to submit load and stress reports will be waived because of the similarity. If the tunnel user and NASA Lewis agree to cooperative publication of the data, the tunnel user may be asked to supply selected model drawings and/or photographs for reproduction in NASA technical papers.

6.3 Model and Equipment Delivery

All models, instrumentation, and support hardware should be delivered to NASA Lewis to the attention of the IRT project engineer (the IRT facility manager will supply the name of this engineer to the tunnel user). To reduce installation delays (see sec. 7.2), all model parts, model internal instrumentation, and tunnel-user support hardware should be assembled prior to shipment to NASA Lewis. Large shipping crates must have skids so they can be handled by forklift trucks (the maximum weight of the model plus the shipping crate should not exceed 3000 lb_f). The delivery date of equipment and models prior to testing will vary according to the complexity of the model installation and the amount of instrumentation to be hooked up to the data-recording system. The tunnel user and the IRT project engineer should agree to an appropriate delivery time.

When shipments leave the customer's plant, the IRT project engineer should be notified of the scheduled arrival date and identifying shipping numbers. Deliveries are accepted at NASA Lewis from 8:00 a.m. to 4:30 p.m. eastern standard time, Monday through Friday, excluding Federal Government holidays. Off-hour delivery can usually be accommodated by an arrangement with the IRT facility manager or the IRT project engineer.

7.0 Risk Assessment of the Wind Tunnel Model and Test Hardware

The following sections discuss permissible model design criteria pertaining to loads and allowable stresses, model fabrication, and quality assurance requirements.

7.1 Model Design Criteria

7.1.1 Model design loads.—It is the responsibility of the tunnel user to work with the model design engineer to establish design loads. Critical loads may occur with the accretion of ice on the model during experiments. The tunnel user should submit the established model design loads and analysis to the IRT project engineer 8 weeks before the scheduled test (see ref. 10, sec. 6.1.2). Safety factors are discussed in section 7.1.3.

7.1.2 Model stress analysis.—The tunnel user must submit a stress analysis to the IRT project engineer 8 weeks before the scheduled test (see ref. 10, sec. 6.1.3). The stress analysis should include (1) dynamic factors that may result from flow separation, (2) thermal stresses due to cold-air experiments, (3) stress concentration factors, and (4) cyclic thermal loads. The calculations should show that the worst-case load does not exceed the allowable stresses.

For each section of the model analyzed, there should be a sketch showing the forces and moments acting on that section. The analysis of each section should list approximations, assumptions, model section properties, and the heat-treat condition of the material. All general equations should be listed before the numerical values are substituted. Shear and moment diagrams should be given for a worst-case load distribution. A sufficient number of model sections should be analyzed to determine allowable shear, axial load, bending, and torsion in order to facilitate finding the critical model section.

7.1.3 Allowable stress.—The models tested in the IRT are usually flight-type hardware, so the allowable stresses must be adjusted to reflect this fact. First, the aeronautical category of the model to be tested must be determined (i.e., military, normal, transport, rotorcraft, utility, commuter, etc.). Then the Federal Aviation Regulations (FAR) for the model category should be consulted to determine the allowable stresses (i.e., factor of safety, strength, and deformation). The stress analysis that is given to the IRT project engineer should cite the specific FAR manual used to determine the allowable stresses on the model.

Thermal stresses that could occur in the model because of the IRT experiments should be subtracted from the ultimate tensile strength and the tensile yield strength before safety factors for allowable stresses are applied. The material properties that are used in calculations should be the expected minimum values.

7.1.4 Stability requirements.—The model stress report (see ref. 10, sec. 6.1.3) should show that the model, mounting points, and restraints are statically and dynamically stable within the model test matrix. It should also discuss the effects of Reynolds number, Mach number, surface conditions, and so forth, in the development of equations noted in the analysis. Also the range of such parameters as mass and inertia and the stiffness coefficients used in the analysis should be noted.

7.1.5 Material selection.—Materials for the model and support structures are to be selected by using the applicable physical and mechanical properties listed in one of the following standards:

(1) American Society for Testing Materials (ASTM)
(2) American Society of Mechanical Engineers (ASME)
(3) Society of Automotive Engineers (SAE)
(4) The Aerospace Structural Metals Handbook from the Department of Defense (DOD)

All material properties should be suitably corrected for temperature.

7.1.6 Structural joints.—All counterbores, spot faces, and countersinks in the model, mounting plate (sec. 2.3), and other support structures must be aligned so as to keep the fasteners from bending due to torquing.

Screws and/or threaded connectors used to join a model to a support structure should be able to withstand torquing at loads greater than the maximum separating forces expected. All structural bolted or screwed connections must have positive mechanical locks such as locking inserts, self-locking nuts, cotter pins, or safety wiring. Bolted joints whose primary function is to transmit moments should be designed so that the bolt preload divided by the joint contact area is at least 1.25 times the applied moment divided by the section modulus.

All welded joints should be designed and fabricated in compliance with the code of the American Welding Society (AWS).

7.1.7 Pressure systems.—Models and support and test equipment using hydraulic, pneumatic, or other systems with operating pressures above 15 psig shall be designed, fabricated, inspected, tested, and installed in accordance with FAR. The FAR manual used should be applicable to the model or support system category defined by the tunnel user. The hydraulic and pneumatic support systems are discussed in the Miscellaneous Equipment section in the FAR manuals.

Pressure-relief devices may be required in a hydraulic or pneumatic system, but not necessarily in the model. These devices should be able to relieve the overpressure by discharging a sufficient flow from the pressure source under the conditions causing the malfunctions.

The IRT facility manager and the IRT project engineer should be given the following information about all components of a pressure system: volume capacity, temperature range, working pressure, and proof pressure. Note that all components of a pressure system should be stored in a clean, dry, and sealed condition after proof testing and before delivery to the IRT.

7.1.8 Pressure piping.—All piping shall be designed, fabricated, inspected, tested, and installed in compliance with the FAR or the American National Standards Institute (ANSI) Piping Code. Powered models that have internal piping and acceptable pressure levels are discussed in Hydraulic Systems in the Miscellaneous Equipment section in the FAR code.

In order to obtain the appropriate FAR manual, the model's category must be determined. Pressure vessels constructed from standard pipe, standard pipe fittings, and standard flanges are also considered pressure piping. For these, acceptable pressure levels are specified in the Hydraulic Systems section.

Allowances for thinning of the pipe wall due to bending and/or threading of the pipe should be in accordance with the ANSI Piping Code. Threaded joints, seal welding of threaded joints, and flange joints must also comply with this ANSI code.

7.1.9 Electrical equipment components.—Because of the harsh environment in the IRT test section, only hardware, equipment, and material conforming to the National Electrical Code may be used. Each set of wires on all pressure transducers, strain gauges, vibration pickups, and other low-voltage devices must be shielded. Details regarding user-supplied control panels and/or control boxes and the associated wiring to the facility control room should be discussed with the IRT electrical engineer at one of the pretest meetings. The format for user-supplied electrical schematics, wiring diagrams, and connectors to interfaces at control panels, control boxes, and/or the model should be discussed with the IRT electrical engineer.

7.2 Model Fabrication Requirements

Models should be completely assembled at the manufacturer's plant, and any discrepancies should be corrected at that time. All model parts must be inspected to ensure proper fit and must be certified for the loads and deflections to be encountered during testing. In addition, all remote control model functions should be checked out, and the position indicators calibrated before shipment to NASA Lewis.

All electrical leads and pressure lines from the model should be clearly identified. The pressure lines must be clean and free of oil and debris and must have been leak-checked at operating pressures.

7.3 Quality Assurance Requirements

Written procedures for model assembly, installation, and configuration changes in the IRT are required. They should be submitted to the IRT project engineer at least 8 weeks before the scheduled test. These procedures should list sequentially the steps to be taken to mount the model in the tunnel test section. They should also indicate the model's alignment in the test section and the bolt torquing values for fastening the model to the mounting plate. The assembly, installation, and checkout of user-supplied hardware should also be addressed. The model installation procedures should be supplemented with the necessary drawings and/or sketches.

8.0 General Information

The following information is provided to familiarize the tunnel user with the services available and the standard operating procedures.

8.1 Logistical Support

8.1.1 Model buildup.—In most instances the models tested in the IRT are not complex, and installation in the tunnel is not an involved procedure. The time by which the model must arrive at the IRT before testing should be discussed with the IRT project engineer.

8.1.2 Space assignment.—The north control room (fig. 2) is available for tunnel users. Figure 20 shows details of the space available in this control room.

8.1.3 User personnel responsibilities.—The tunnel user's own mechanics and technicians must install the model in the tunnel, along with the required instrumentation; they must also set up any custom data systems. All tools, spare parts, special equipment, and supplies necessary to work on the model and ancillary systems must be provided by the tunnel user. A tunnel-user aerodynamist familiar with the model and the test objectives must be present during testing.

8.1.4 Operation of Government equipment.—Tunnel-user personnel may not operate Government-furnished equipment or make connections to this equipment without the approval of a NASA Lewis civil servant.

8.1.5 Tunnel safety.—Tunnel users may enter the tunnel test section only after they are given permission by the IRT project engineer or a qualified IRT tunnel operator. Care must be taken while examining the model in the test section to preclude injury from sharp edges on the model due to ice accretion or from instrumentation probes and/or rakes that may be positioned in the tunnel test section (see sec. 9.1). The test-section floor is slippery after a run, so caution should be exercised when entering the test section (see sec. 9.1). All persons entering the tunnel for an extended period of time should wear the proper protective cold-weather clothing (see sec. 9.2).

8.1.6 Support during tests.—All tunnel-user requests for manpower assistance and shop or facility services should be submitted by the tunnel user to the IRT project engineer.

8.2 Operations

8.2.1 Normal operating days and shift hours.—The facility is staffed for a two-shift operation. The first shift (8 a.m. to 4 p.m.) is reserved for model work and facility checkout. During the second shift (4 p.m. to midnight), tests are run between 4:30 p.m. and 11:30 p.m., Monday through Friday. This test window can be expanded for an ambitious test schedule by requesting an early start. Tunnel users should discuss extending the test time with the IRT facility manager and the IRT project engineer.

8.2.2 Off-shift coverage.—Access to the IRT at times other than operating shifts must be coordinated with the IRT project engineer.

8.3 Planning

8.3.1 Prerun safety meeting.—The IRT project engineer will prepare a Safety Permit Request describing the safety aspects of the tests as well as the test objectives, run schedule, instrumentation, and hardware. The Safety Permit Request package is then sent via the IRT facility manager to the Center's Safety Assurance Office, the Office of Environmental Programs (if applicable), and the IRT Facility Safety Committee for their review and approval. The Safety Permit Request should be completed and available for review at least 12 weeks prior to the start of testing.

The following is a list of conditions that would require special action by the IRT Facility Safety Committee:

(1) Use of radioactive materials or gases
(2) Use of high-speed rotating model parts without suitable shrouds
(3) Ejection into the tunnel circuit of material or gases that may cause an explosion
(4) Use of toxic materials (Material Safety Data Sheets must be provided. At one of the pretest meetings, the IRT project engineer can advise the tunnel user about the acceptability of model materials.)

8.3.2 Test time.—The tunnel test time charged to a non-NASA-user's experiment will include the total time that the facility is available to the user, that is, time for model and instrumentation installation and removal, the experiment time, and time for returning the tunnel and associated areas to their pretest condition. The time required to crate the user's model and equipment for shipment must also be included.

Extensions to a test window may be granted. This point is negotiable between the tunnel-user's lead engineer and the IRT facility manager. Discussions with NASA Lewis personnel who have experience with the facility should enable the tunnel user to make a fairly accurate estimation of the time required to complete the test program.

8.3.3 NASA debriefing.—Prior to completion of the test program, the tunnel-user's lead engineer shall meet with the IRT facility manager to evaluate the test support received by the tunnel user during the test program. The IRT facility manager will make arrangements for the meeting.

8.4 Security Notification Requirements

The amount of advance notice required to obtain access to the IRT at NASA Lewis Research Center depends on the classification of the test program and characterization of the non-NASA visitor.

8.4.1 Nonclassified test by a U.S. citizen.—For nonclassified test programs, the IRT project engineer will notify the NASA Lewis Visitor Control Center at least 3 days prior to the arrival of a non-NASA visitor who is a U.S. citizen. The following visitor information is required: (1) the name of the visitor, (2) the visitor's place of employment, (3) the purpose of the visit and the associated dates, and (4) the NASA Lewis contact person and the escort.

8.4.2 Nonclassified test by a non-U.S. citizen.—Non-U.S. citizens should make arrangements with their embassy in Washington, DC, at least 1 month prior to their intended visit to NASA Lewis. The appropriate embassy should work with NASA Headquarters in Washington, DC (International Planning and Programs Office—Code IRD), to establish the necessary clearances. Non-U.S. citizens will require an escort at all times in the facility.

8.4.3 Sensitive test by a U.S. citizen.—A sensitive test program at NASA Lewis may be conducted only by a U.S. citizen. For such tests the proper security clearance must be in place prior to the arrival at Lewis of a non-NASA U.S. citizen. The NASA Lewis Security Office must receive a Visit Notification Letter from the visitor's company. This letter is to include the following information for each visitor:

(1) Social Security number
(2) Full name
(3) Date and place of birth
(4) Security clearance level
(5) Date clearance was granted
(6) Who granted the clearance
(7) Date and duration of visit
(8) NASA contact

Visit Notification Letters are to be sent to the following address:

NASA Lewis Research Center
ATT.: Security Office
Mail Stop 21-5
21000 Brookpark Road
Cleveland, OH 44135
Phone: (216) 433-3025
FAX: (216) 433-6664

The IRT project engineer will notify the NASA Lewis Security Office and the Visitor Control Center 3 days prior to the arrival of non-NASA visitors who are participating in a sensitive test program at the Center.

9.0 Personnel Safety

The following information is provided to acquaint the tunnel user with tunnel test-section and facility control-room safety.

9.1 Hazards

Tunnel-user personnel should be aware of the following hazards:

(1) The facility control rooms are located within the facility balance chamber (see fig. 2). Since the noise levels in the balance chamber may be high during tunnel testing, there may be noise problems in the control rooms. In such cases, hearing protectors (provided by NASA Lewis) may be required.

(2) Models installed in the tunnel test section may have sharp edges due to their design and fabrication and/or the accretion of ice during testing. The tunnel users and the IRT project engineer should discuss tunnel test-section safety associated with the model at one of the pretest meetings.

(3) The test-section floor is often wet and slippery as a result of using the spray bars during a tunnel test or from melting ice and/or condensation. Tunnel users should not enter the test section to examine the model after a test run until they have the permission of the IRT project engineer or a qualified tunnel operator. Tunnel users entering the test section after a test run must wear appropriate shoes and be careful of their footing.

(4) Abrupt pressure changes during normal tunnel operation affect the pressure in the balance chamber and in both control rooms and may cause some discomfort to personnel.

(5) The tunnel-user's senior engineer is responsible for ensuring that all members of the user team are accounted for prior to closing the access hatch to the tunnel test section.

All first-time tunnel users/visitors must take the mandatory safety briefing given by the IRT project engineer or the IRT mechanics crew chief. Additional hazards associated with a particular test will be discussed with tunnel users by the IRT facility manager and the IRT project engineer at one of the pretest meetings.

9.2 Protective Equipment

Tunnel users must observe the guidelines regarding the use of protective equipment and clothing during a test program. The user may require protective hearing equipment while working in the balance chamber when the tunnel is operating. When the model is being examined between runs, the user should wear cold-weather clothing and gloves (both supplied by NASA Lewis).

9.3 Emergency Procedures

The IRT facility has specific operating procedures to protect tunnel personnel, the facility, and computing equipment in case of emergency. The IRT project engineer will discuss these procedures with the tunnel user at the pretest meeting.

9.4 Working Alone

Inside the tunnel, users should always work in groups of at least two people—never alone. Working alone is defined as working out of audio or visual contact with a coworker for more than 5 minutes. Working alone is not permitted unless approval is obtained from the IRT project engineer.

10.0 Appendix A

IRT Contact Person

The following individual is the key contact person at the IRT facility. Mail correspondence can be addressed as follows:

NASA Lewis Research Center
ATT.: IRT Facility Manager
Mail Stop 6-8
21000 Brookpark Road
Cleveland, OH 44135

The name of the IRT facility manager can be obtained from a NASA Lewis telephone directory. This information is presented in the organizational listing under Aeropropulsion Facilities and Experiments Division, Facilities Management Branch (organizational code 2810). In the absence of a directory, call (216) 433-4000 (NASA Lewis switchboard operator) and ask the operator to supply the name of the facility manager. The telephone number at the IRT Facility is (216) 433-2052.

Customer models and equipment can be shipped to the following address:

NASA Lewis Research Center
ATT.: IRT Facility Manager
Mail Stop 11-1
21000 Brookpark Road
Cleveland, OH 44135

11.0 Appendix B

Procedure for Obtaining Tunnel Test Time

The following is a summary of the process for obtaining tunnel test time:

(1) At least 1 year before the test, the tunnel user contacts the IRT facility manager and submits the overall test requirements.

(2) The IRT facility manager and the appropriate AFED personnel review the request.

(3) The tunnel user submits a formal letter of request to the Director of Aeronautics at NASA Lewis (non-NASA requesters only).

(4) If the project is accepted, a test agreement is prepared and signed by the requester (applies to non-NASA requesters only).

(5) Pretest meetings are held to discuss the test plan, instrumentation, tunnel hardware, and data requirements.

Attendees are the requester and key tunnel-user personnel, the IRT facility manager, appropriate AFED branch chiefs, key AFED personnel, and the IRT project engineer.

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13. ABSTRACT ***(Maximum 200 words)***

This manual describes the Icing Research Tunnel (IRT) at the NASA Lewis Research Center and provides information for users who wish to conduct experiments in this facility. The capabilities of the tunnel test section, main drive system, speed control system, and spray bars are described. Tunnel performance maps of liquid water content as a function of median volume droplet size is presented for two types of spray nozzles at test-section velocities ranging from 86.8 to 303.9 kn (100 to 350 mph). The facility support systems, which include heated air systems, steam and service air systems, an altitude exhaust system, a force balance system, and the model electrical power system, are described. Also discussed are facility instrumentation capabilities for temperature and pressure measurements and model attitude simulation. In addition, photographic documentation and flow visualization techniques are explained, and pretest meeting formats and schedules are outlined. Tunnel-user responsibilities, personnel safety requirements, and types of test agreements are explained. The IRT is a closed-return atmospheric tunnel with a test section that is 6 ft high, 9 ft wide, and 20 ft long. It is equipped to support testing at airspeeds up to 303.9 kn (350 mph) with a 5.0-percent blockage model in the test section in a temperature and water-droplet environment that simulates natural icing conditions.

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